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JAN 81 J N DEMARCHI, R K HANING N62269-78-C-0363
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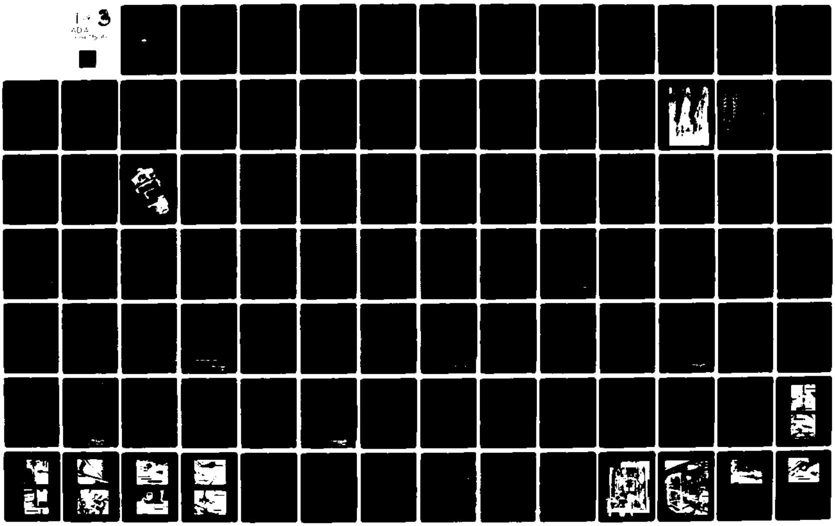

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LEVEL II

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DESIGN, DEVELOPMENT, AND EVALUATION OF LIGHTWEIGHT HYDRAULIC SYSTEM HARDWARE - PHASE I

Rockwell International

North American Aircraft Division
4300 East Fifth Avenue
P.O. Box 1259
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JANUARY 1981

FINAL REPORT FOR PERIOD 16 AUGUST 1978–30 JANUARY 1981

Approved for Public Release
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Prepared For

NAVAL AIR SYSTEMS COMMAND
Department of the Navy
Washington, DC 20361

NAVAL AIR DEVELOPMENT CENTER
Aircraft and Crew Systems Technology Directorate
Warminster, PA 18974

This technical report has been reviewed and is approved for publication.

APPROVED BY: Edward J. Sturm DATE: 3-12-81

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NADC-77108-30 ✓	2. GOVT ACCESSION NO. AD-A097 505	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DESIGN, DEVELOPMENT, AND EVALUATION OF LIGHTWEIGHT HYDRAULIC SYSTEM HARDWARE - PHASE I		5. TYPE OF REPORT & PERIOD COVERED Final Report 16 August 1978 - 30 January 1981
		6. PERFORMING ORG. REPORT NUMBER NR81H-2
7. AUTHOR(s) Joseph N. Demarchi Robert K. Haning		8. CONTRACT OR GRANT NUMBER(s) N62269-78-C-0363 NEW
9. PERFORMING ORGANIZATION NAME AND ADDRESS Rockwell International Corporation North American Aircraft Division 4300 E. Fifth Ave., Columbus, Ohio 43216		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command (AIR-340C) Department of the Navy Washington, D.C. 20361		12. REPORT DATE January 1981
		13. NUMBER OF PAGES 234
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Air Development Center (6061) Warminster, Pennsylvania 18974		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft Hydraulic Systems
Lightweight Hydraulic Systems
Very High Pressure Hydraulic Systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Lightweight Hydraulic System (LHS) program assesses the advantages of using an 8000 psi operating pressure level in Navy aircraft instead of the conventional 3000 psi level. This report presents the results of Phase I of a program to design, fabricate, and test a full scale 8000 psi system in a ground simulator and A-7E flight test aircraft. Two independent lightweight hydraulic systems, powered by variable delivery 8000 psi pumps, utilize twenty 8000 psi actuators and fourteen types of LHS minor hardware items. A steel framework

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20. ABSTRACT (Continued)

ground simulator was designed with LHS component installation and hydraulic distribution systems similar to the A-7E aircraft. Laboratory tests conducted on components fabricated in Phase I include rod seal development, servo valve erosion, compatibility, pressure impulse, and endurance. A math model of the compatibility system was verified. Test results demonstrated that the Phase II simulator will function as designed. Weight and space analyses made on LHS components projected the 30% weight and 40% space saving goals can be achieved. Based on preliminary R&M assessments of the development hardware, the MFHBF and MMH/FH improvements goal of 15% will be obtained.

EXECUTIVE SUMMARY

1.0 PURPOSE OF THE PROGRAM

Aircraft hydraulic power requirements have increased significantly in recent years due to higher aerodynamic loading and expanded hydraulic functions. Weight and space allocations available for hydraulic system components have decreased because of thinner airfoil designs and the increasing number of on-board systems. Substantial reductions in the weight and space requirements of hydraulic components must be accomplished to meet mission and performance demands of future Navy aircraft. The Lightweight Hydraulic System (LHS) program investigates the concept of using higher operating pressures to achieve smaller and lighter weight hydraulic components.

2.0 BENEFITS TO THE NAVY

The LHS Advanced Development Program will assess the advantages of using an 8000 psi operating pressure level instead of the conventional 3000 psi level. This will be accomplished by (1) demonstrating the reliability and maintainability of 8000 psi hydraulic systems, and (2) substantiating the predicted weight and space savings achieved by operating at 8000 psi.

Ultimate goals for lightweight hydraulic systems in Navy aircraft are:

(1) Weight savings of 30% over conventional 3000 psi systems

(2) Space savings of 40% over conventional 3000 psi systems

(3) A 15% improvement in MFHBF for development hardware over current fleet 3000 psi systems

(4) A 15% improvement in MMH/FH for development hardware over current fleet 3000 psi systems

3.0 BACKGROUND INFORMATION

The Navy initiated an Exploratory Development Program in 1966 to investigate the areas of operational practicality and potential weight and space savings achieved by using a pressure level higher than 3000 psi. The program included a feasibility study, component development and testing, selection of the operating pressure level (8000 psi), laboratory systems testing, and brief flight testing. The program established: (1) that 8000 psi lightweight hydraulic systems can be designed, fabricated, and maintained without special techniques or state-of-the-art advances; and (2) that the overall weight and volume of aircraft hydraulic systems can be reduced up to 30% and 40%, respectively, for systems delivering more than approximately 100 horsepower.

The LHS Advanced Development Program will design, fabricate, and test a full scale 8000 psi lightweight hydraulic system on a ground simulator. The system will then be installed on an A-7E test aircraft and flown to assess in-flight performance. The program is anticipated to be performed in three phases:

Phase I	Design, fabricate, and test 8000 psi components
Phase II	Fabricate ground simulator. Conduct performance and endurance tests
Phase III	Install 8000 psi hydraulic system in an A-7E aircraft and conduct flight test program

This report covers Phase I.

4.0 PHASE I SUMMARY

4.1 System, Component, and Simulator Design

Hydraulic circuitry in the A-7E flight test aircraft was reconfigured from three independent power control systems operating at 3000 psi (PC-1, PC-2, and PC-3) to two independent 8000 psi flight control systems (FC-1 and FC-2) and one 3000 psi utility system. FC-1 and FC-2 have the following primary flight control actuators: aileron, spoiler/deflector, roll feel, rudder, and unit horizontal tail (UHT). Secondary flight controls include the speed brake and wing leading edge flaps. The automatic flight control system (AFCS) has three actuators: roll, pitch, and yaw. The A-7E emergency power package (ram air turbine) pump provides emergency power at 3000 psi for FC-2 system.

The lightweight hydraulic system contains a total of 20 actuators; five were fabricated in Phase I. The LHS actuators were designed for the same end attach points, kinematics, load, stroke, and rate requirements as the equivalent 3000 psi actuators. Conventional design techniques and fabrication procedures were employed for all the test units. The 8000 psi pump is a typical variable delivery in-line piston design with several unique features to optimize performance at 8000 psi. LHS minor components such as check valves, filters, and solenoid valves utilized conventional designs modified for 8000 psi service. FC-1 and FC-2 tubing and fittings were sized to reflect the lower flow requirements which result from operating at 8000 psi.

Development of the various LHS components was completed satisfactorily with the exception of the pump. The pump problems were principally quality control and transfer tube sealing.

A full scale ground simulator was designed. The simulator will be a steel frame structure with LHS component installations and hydraulic distribution systems similar to the flight test aircraft. Modular construction provides cost effectiveness and program flexibility. Two types of modules are employed: (1) power system modules, and (2) actuator load modules. Six modules were fabricated in Phase I.

4.2 Specifications

A total of 34 preliminary specifications were written to establish requirements for lightweight hydraulic systems. General, component, and process specifications were prepared in accordance with MIL-STD-961.

4.3 Component Testing

4.3.1 Seal Development - A 400 hour test was conducted to evaluate and select candidate rod seals for the LHS actuators. The investigation considered single stage seals and two-stage unvented seals. Five seal configurations completed the test with acceptable leakage rates. A two-stage seal was selected for use in flight control actuators; a single stage seal was chosen for utility applications. A concurrent evaluation of servo valve erosion was made during the seal test. Erosion should not be a problem in 8000 psi systems using MIL-H-83282 fluid.

4.3.2 Compatibility Test - The compatibility test integrated major sections of the 8000 psi system to be assembled on the full scale simulator in Phase II. Primary purposes of this test were:

(1) Permit preliminary LHS component compatibility testing.

(2) Provide a means for realistically endurance testing the LHS pumps, reservoirs, actuators, valves, etc.

The test was performed in three blocks of 50 hours duration (150 hours total). Actuator cycling was based on the load/stroke schedule given in MIL-C-5503. A total of 1,000,000 cycles were run. Component performance checks were made at 0, 50, 100, and 150 hours.

Because of development difficulties, "interim pumps" were used. These units functioned well but had performance areas which could be improved with design changes. Full performance pumps are anticipated for Phase II.

The compatibility test was completed satisfactorily except for a number of minor problems. The test systems were stable, actuator operation was satisfactory, and pressure fluctuations were low. The results provided convincing evidence that the Phase II simulator will function as designed.

4.3.3 Pressure Impulse Test - A system containing an LHS solenoid valve, quick disconnect, hose, tubing, and 17 fittings was built. Difficulty was experienced in developing the required surge with this setup. After several setup modifications and elimination of the hose, the correct surge was attained (135% of system pressure). A 40,000 cycle test was run. No significant failures occurred.

4.3.4 Component Endurance Test - A 10,000 cycle endurance test was conducted on nine LHS components: accumulator, 3 check valves, hose, manifold, pressure gage, relief valve, and solenoid valve. Pressure was cycled up to 9000 psi to operate the relief valve. All components successfully withstood the test except the solenoid valve and two check valves. Design changes are expected to correct the performance deficiencies.

4.4 Math Model

A computer program based on one developed by the Air Force was used to model the test system and predict pressure pulsation amplitudes. Spectrum scans were run on the compatibility setup. The test data compared well with the predicted values. Pressure pulsation amplitudes were less than the maximum allowable ±200 psi. The data were subsequently corroborated by the Air Force Flight Dynamics Laboratory using their test equipment.

4.5 Weight and Space Analysis

Weight savings achieved in the A-7E lightweight hydraulic system were:

Total weight of EQUIVALENT 3000 psi system		644.4 lb	
Total weight of LHS system		449.7 lb	
	Weight reduction	194.7 lb	
	Weight savings		30.2%

Space savings achieved were:

Total volume of EQUIVALENT 3000 psi system		8173 in^3	
Total volume of LHS system		5207 in^3	
	Volume reduction	2966 in^3	
	Space savings		36.3%

4.6 R&M Assessment

Based on analysis of the development hardware, improvements of 44% in system MFHBF and 17% in MMH/FH were projected. Although the program goal of 15% improvement in system R&M for development hardware appears to have been exceeded, the predicted values must be considered as preliminary.

4.7 GSE Interface Requirements

Hydraulic ground support equipment requirements for aircraft with lightweight hydraulic systems are the same as for aircraft with 3000 psi systems except for operating pressure level. For cost effectiveness, existing and modified equipment are planned to be utilized to the maximum extent possible.

5.0 CONCLUSIONS

Major advances toward attaining the goals of the LHS program were made in Phase I. A principal achievement was the successful operation of two 8000 psi hydraulic systems containing many of the components to be installed in the Phase II full scale simulator. The 150 hour compatibility test demonstrated that an 8000 psi operating pressure level is a practical concept. Weight and space savings--the basic purpose of the LHS program--were determined to be close to predicted values. Work accomplished in Phase I will provide a sound basis for successful implementation of the tasks planned in Phase II.

6.0 RECOMMENDATIONS

Preparations for the construction of an A-7E full scale lightweight hydraulic system simulator were completed in Phase I. Tasks recommended to be performed in Phase II are:

Task I	Fabricate remaining LHS components
Task II	Fabricate LHS simulator
Task III	Conduct simulator tests
Task IV	Component redesign/retest
Task V	Math model development/verification
Task VI	System weight and space analysis
Task VII	Specification update
Task VIII	R&M assessment
Task IX	GSE requirements
Task X	LHS Pump Development

PREFACE

This report documents a development program conducted by Rockwell International Corporation, North American Aircraft Division, Columbus, Ohio, under Contract N62269-78-C-0363 with the Naval Air Development Center, Warminster, Pennsylvania. Technical direction was administered by Mr. J. Ohlson, Head, Materials Application Branch, Aircraft and Crew Systems Technology Directorate, Naval Air Development Center (6061), and Mr. S. Hurst, Assistant Technology Administrator, Naval Air Systems Command (AIR-340C).

This report presents the results of Phase I of a program to design, fabricate, and test a full scale 8000 psi Lightweight Hydraulic System in a ground simulator and A-7E flight test aircraft. This work is related to tasks performed under Contracts NOw-65-0567-d, N00019-68-C-0352, N00156-70-C-1152, N62269-71- C-0147, N62269-72-C-0381, N62269-73-C-0700, N62269-74-C-0511, N62269-75-C- 0422, N62269-76-C-0254, and N62269-78-C-0005.

Vought Corporation, Dallas, Texas, and Sperry-Vickers, Jackson, Mississippi, were major subcontractors on the program.

Project engineers in Phase I of the LHS Advanced Development Program were:

Mr. J. Demarchi	North American Aircraft Division
Mr. K. Fling	Vought Corporation
Mr. F. Perian	Sperry-Vickers

Appreciation is extended to the many individuals who provided helpful support and constructive criticism of the program; in particular, Mr. S. Hurst and Mr. N. Webb of the Naval Air Systems Command, Mr. J. Ohlson and Mr. J. Dever of the Naval Air Development Center, and Mr. E. Culp of the North American Aircraft Division.

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1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

Most military and commercial aircraft flying today have hydraulic systems which operate at 3000 psi. This pressure level was flown for the first time in the early 1940's and has remained at that level despite significant advances in sealing technology, pump and actuator design, fluids, and materials. Aircraft hydraulic power requirements have increased from less than 10 horsepower in early systems to 300 hp on the Navy F-14 fighter, and 1000 hp on the Air Force B-1 bomber. This growth has resulted primarily from higher aerodynamic loading combined with increased hydraulic functions and responsibilities. As airfoil designs have become thinner and mission requirements have continued to expand, internal volume available for the installation of all systems has decreased. Thus, while more and more power is allocated for hydraulic functions, smaller weight and space allocations are available for system components. Significant reductions in the weight and space requirements of hydraulic components must be accomplished to meet mission and performance demands of future Navy aircraft.

The concept of using higher operating pressures to achieve smaller and lighter weight hydraulic components is logical and warranted an in-depth investigation. The Navy initiated an exploratory development program in 1966 to assess the areas of operational practicality and potential weight and space savings. The program included a feasibility study, component development and testing, selection of the operating pressure level (8000 psi), laboratory systems testing, and brief flight testing, References 1 through 10. The program established: 1) that 8000 psi lightweight hydraulic systems can be designed, fabricated, and maintained without special techniques or state-of-the-art advances; and 2) that the overall weight and volume of aircraft hydraulic systems can be reduced up to 30% and 40%, respectively, for systems delivering more than approximately 100 horsepower.

1.2 PROGRAM OBJECTIVES

The program overall objectives are: 1) to demonstrate the reliability and maintainability of 8000 psi hydraulic systems; and 2) to substantiate the predicted weight and space savings achieved by operating at 8000 psi. These objectives are to be accomplished by designing, fabricating, and testing a full scale 8000 psi lightweight hydraulic system on a ground simulator to assure satisfactory operation. The system will then be installed on an A-7E test aircraft and flown to assess in-flight performance.

Ultimate goals for lightweight hydraulic systems in Navy aircraft are:

(1) Weight savings of 30 percent over conventional 3000 psi systems

(2) Space savings of 40 percent over conventional 3000 psi systems

(3) A 15 percent improvement in MFHBF for LHS development hardware over current fleet 3000 psi systems

(4) A 15 percent improvement in MMH/FH for LHS development hardware over current fleet 3000 psi systems.

The program is anticipated to be performed in three phases:

Phase I	- Design, fabricate, and test 8000 psi components
Phase II	- Fabricate ground simulator. Conduct performance and endurance tests
Phase III	- Install 8000 psi hydraulic system in an A-7E aircraft and conduct flight test program.

1.3 PHASE I SCOPE OF WORK

The scope of work in Phase I is summarized below:

Task I	Design the 8000 psi flight control system to be tested in an A-7E aircraft.
Task II	Prepare preliminary military specifications for 8000 psi components and systems.
Task III	Design 8000 psi components. Fabricate selected components.
Task IV	Conduct component testing including seal development, valve erosion, acceptance, endurance, impulse, and compatibility.
Task V	Assess R&M from test program data.
Task VI	Design ground simulator. Design and fabricate selected subsystem modules.
Task VII	Develop preliminary math models for hydraulic and thermal system characteristics.
Task VIII	Verify projected weight and space savings to be achieved.
Task IX	Determine GSE interface requirements and make recommendations for equipment to be utilized in follow-on phases.

Drawings and specifications developed in Tasks I, II, III, and VI were submitted to the Navy Project Office under separate cover, References 11 and 12.

1.4 SUBCONTRACTING

Fifteen suppliers were awarded subcontracts to support the LHS Advanced Development Program in Phase I. Two firms provided major support: Vought Corporation, Dallas, Texas, and Sperry-Vickers, Jackson, Mississippi.

Vought Corporation is a prime manufacturer of military aircraft and built the flight test aircraft to be used in the LHS program. Vought provided important support in several areas:

- Supplied technical information on the A-7E
- Conducted seal development and servo valve erosion tests
- Designed and fabricated flight control actuators and system reservoirs
- Conducted acceptance testing of actuators and reservoirs
- Conducted limited endurance testing of actuators

Sperry-Vickers is a major manufacturer of aircraft hydraulic pumps. This firm developed the variable delivery pumps used to power the 8000 psi test systems.

2.0 SYSTEM DESIGN

2.1 A-7E AIRCRAFT

2.1.1 General Description

The A-7E Corsair II is a single-place light attack aircraft powered by a turbojet engine, Figure 1. It is designed for both land and carrier based operations and employs advanced radar, navigation, and weapons systems. The aircraft has sweptback wings with a marked degree of negative dihedral. The primary flight control surfaces are ailerons, spoiler/deflectors, rudder, and unit horizontal tail (UHT). Secondary flight controls include the speed brake and wing leading and trailing edge flaps. Automatic flight control systems (AFCS) are provided for the roll, pitch, and yaw axes.

2.1.2 Hydraulic System

Prior to Airframe Change No. 73, the A-7E had two independent hydraulic systems, PC-1 and PC-2, which performed both flight control and utility functions. After Airframe Change No. 73, the A-7E contained three systems, PC-1, PC-2, and PC-3, which were integrated to power the flight control and utility systems. The objective of this configuration was to provide improved aircraft survivability. The flight test aircraft will have the 3-system configuration.

The A-7E hydraulic systems operate at 3000 psi and are designed to MIL-H-5440 Type II (-65 to +275°F) requirements. The primary flight control surfaces are powered by dual tandem hydraulic actuators. Each half of the tandem actuators is pressurized by two of the three power control systems as shown in Figure 2. If one PC system fails, the other two systems continue to supply hydraulic power for flight. An emergency power package (EPP) hydraulic pump provides emergency power for the PC-3 system.

The flight control system pumps are constant pressure, variable delivery, in-line piston designs with the following capacities:

PC-1	24.1 gpm at 5650 rpm
PC-2	40.3 gpm at 5650 rpm
PC-3	15.6 gpm at 4400 rpm

MIL-H-5606 hydraulic fluid is supplied to each pump by airless, bootstrap type reservoirs pressurized by system pressure (3000 psi). Fluid cleanliness is maintained by 5 micron absolute filters. Reservoir and system fluid capacities are:

	Reservoir	System
PC-1	0.8 gal.	3.5 gal.
PC-2	4.0 gal.	12.4 gal.
PC-3	0.8 gal.	3.5 gal.

FIGURE 1. A-7E Corsair II

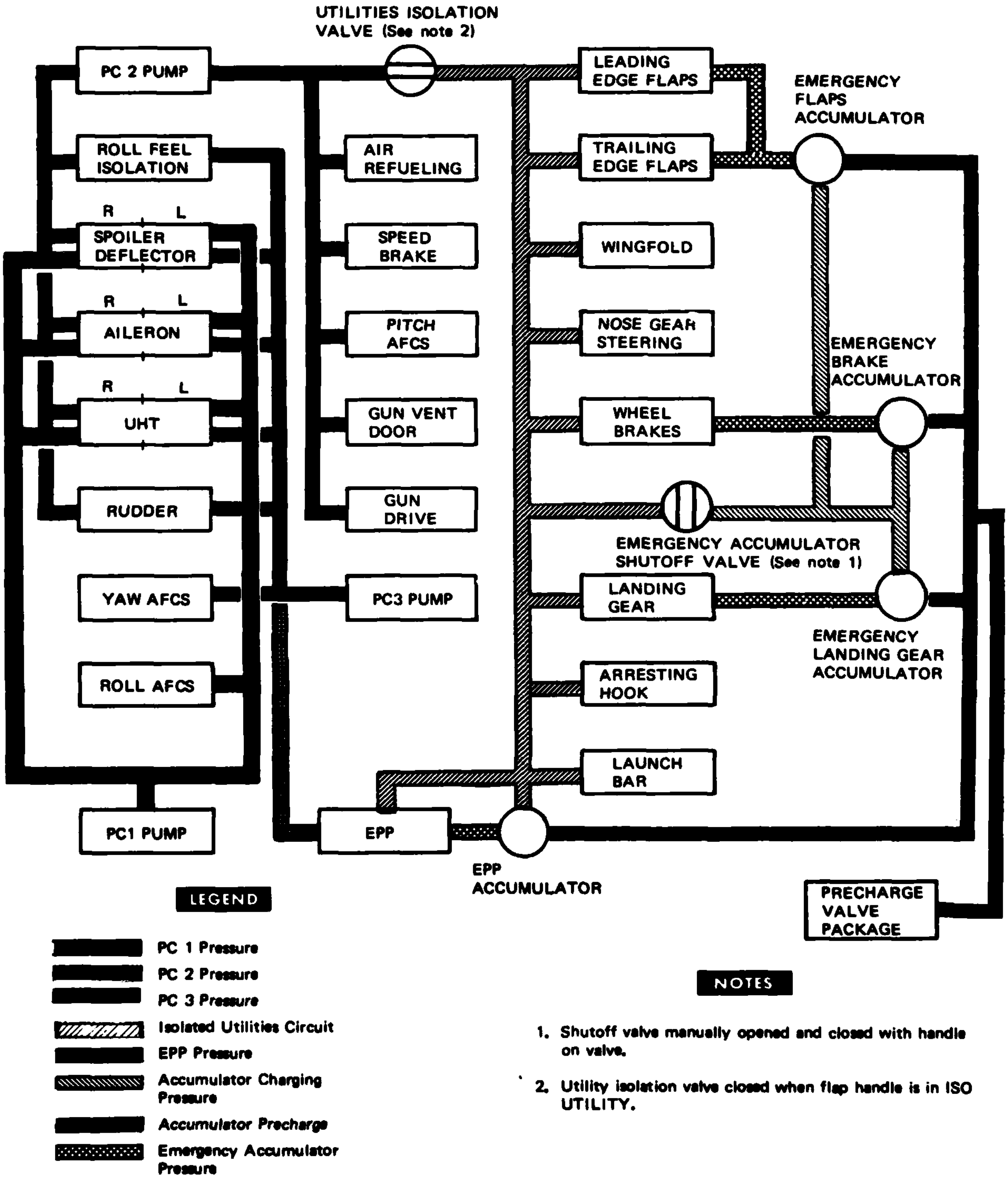


FIGURE 2. A-7E hydraulic system

2.2 A-7E LIGHTWEIGHT HYDRAULIC SYSTEM

Hydraulic circuitry in the A-7E flight test aircraft was re-configured from three independent power control systems operating at 3000 psi (PC-1, PC-2, and PC-3) to two independent 8000 psi flight control systems (FC-1 and FC-2) and one 3000 psi utility system. A simplified block diagram of the test installation is shown in Figure 3. A detail schematic diagram is presented as Figure 5. Major changes made in the A-7E hydraulic systems were:

- MIL-H-5606 fluid replaced with MIL-H-83282 fluid.
- PC-1 and PC-2 3000 psi pumps replaced with FC-1 and FC-2 8000 psi pumps. FC-1 and FC-2 pumps power flight control functions only.
- PC-3 3000 psi pump powers utility functions only.
- PC-2 reservoir converted to utility system reservoir.
- PC-3 reservoir converted to FC-2 reservoir.
- Speed brake hydraulic circuitry moved from PC-2 to FC-1.
- EPP supplies emergency 3000 psi power to FC-2.
- Seven primary and thirteen secondary flight control 3000 psi actuators replaced with 8000 psi actuators.

All FC-1 and FC-2 tubing and fittings were sized to reflect the lower flow requirements which result from operating at 8000 psi. Pressure tubing used in Phase I was 21-6-9 CRES; return tubing was 6061-T6 aluminum. Standard MS 28778 O-rings were used in all static (boss) seals. Component details are discussed in Section 3.0.

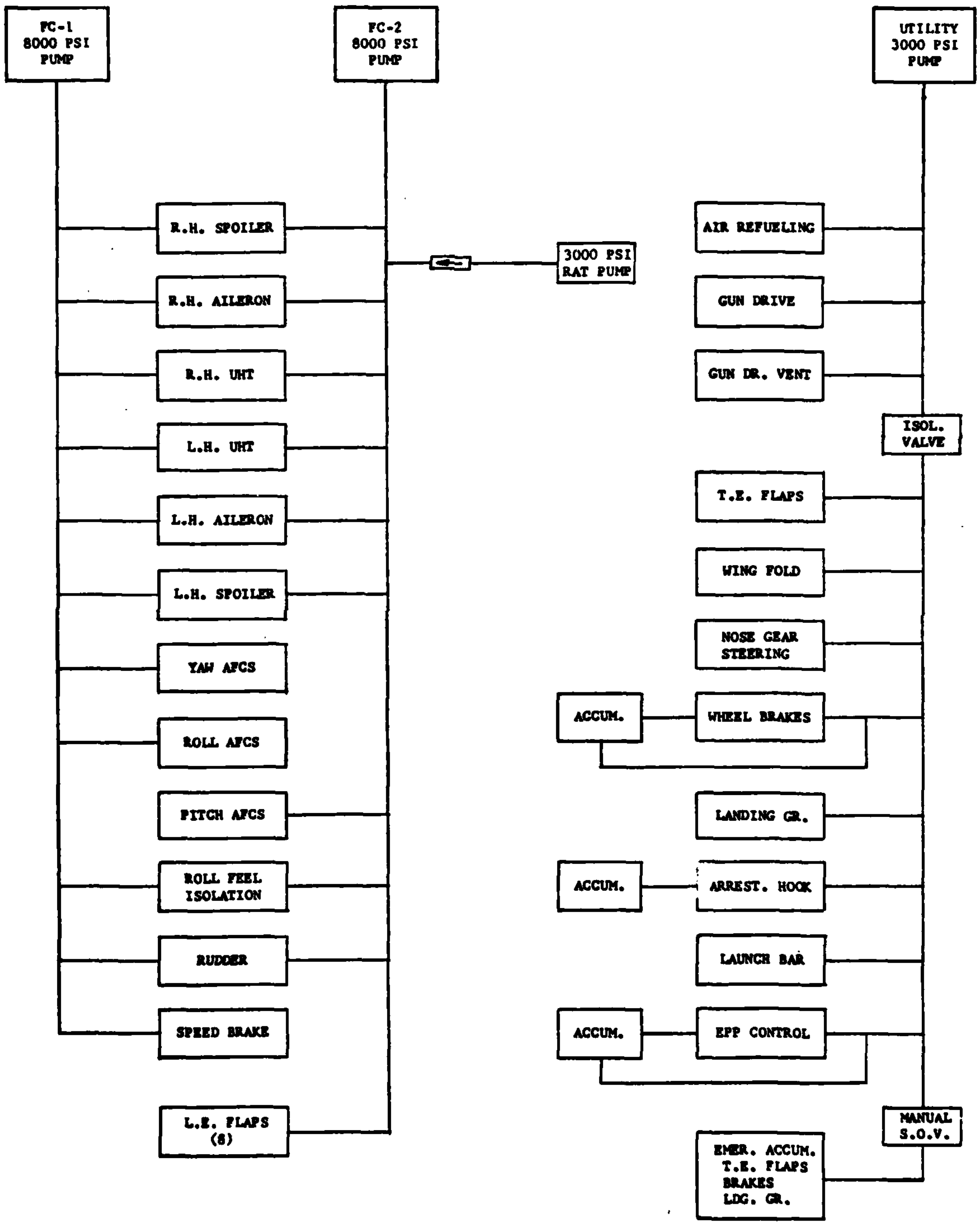


FIGURE 3. A-7E lightweight hydraulic system

3.0 COMPONENT DESIGN

3.1 MAJOR COMPONENTS

3.1.1 Pump

The LHS pump was designed and fabricated by Sperry-Vickers in Jackson, Mississippi, and is identified as M/N PV3-047-2, P/N 570937. The unit is a variable delivery pressure compensated in-line piston design, Figure 4. Rated output at 5900 rpm and +220°F inlet fluid temperature is 10 gpm at 7700 psig; full displacement is 0.47 CIPR. Port sizes are: -10 inlet, -8 discharge, and -6 case drain.

The pump is basically a conventional design with several unique features to optimize performance at 8000 psi, Figure 6. Thick walled pistons are used to reduce unswept volume. The heavier pistons produce higher centrifugal moments than those occurring in 3000 psi pumps. In order to reduce the drive shaft bending stresses, meet the allowable shaft slope through the pump bearings, and absorb piston inertia moments, the cylinder block and drive shaft are integrated into a single piece. Because of the stiffness of the cylinder block drive shaft, a floating plate is used for valving the cylinders into the valve block. This plate is driven by the cylinder block through nine transfer tubes. The swash plate/piston shoe configuration in essentially a conventional design.

3.1.2 Actuators

LHS actuators designed and fabricated in Phase I were as follows:

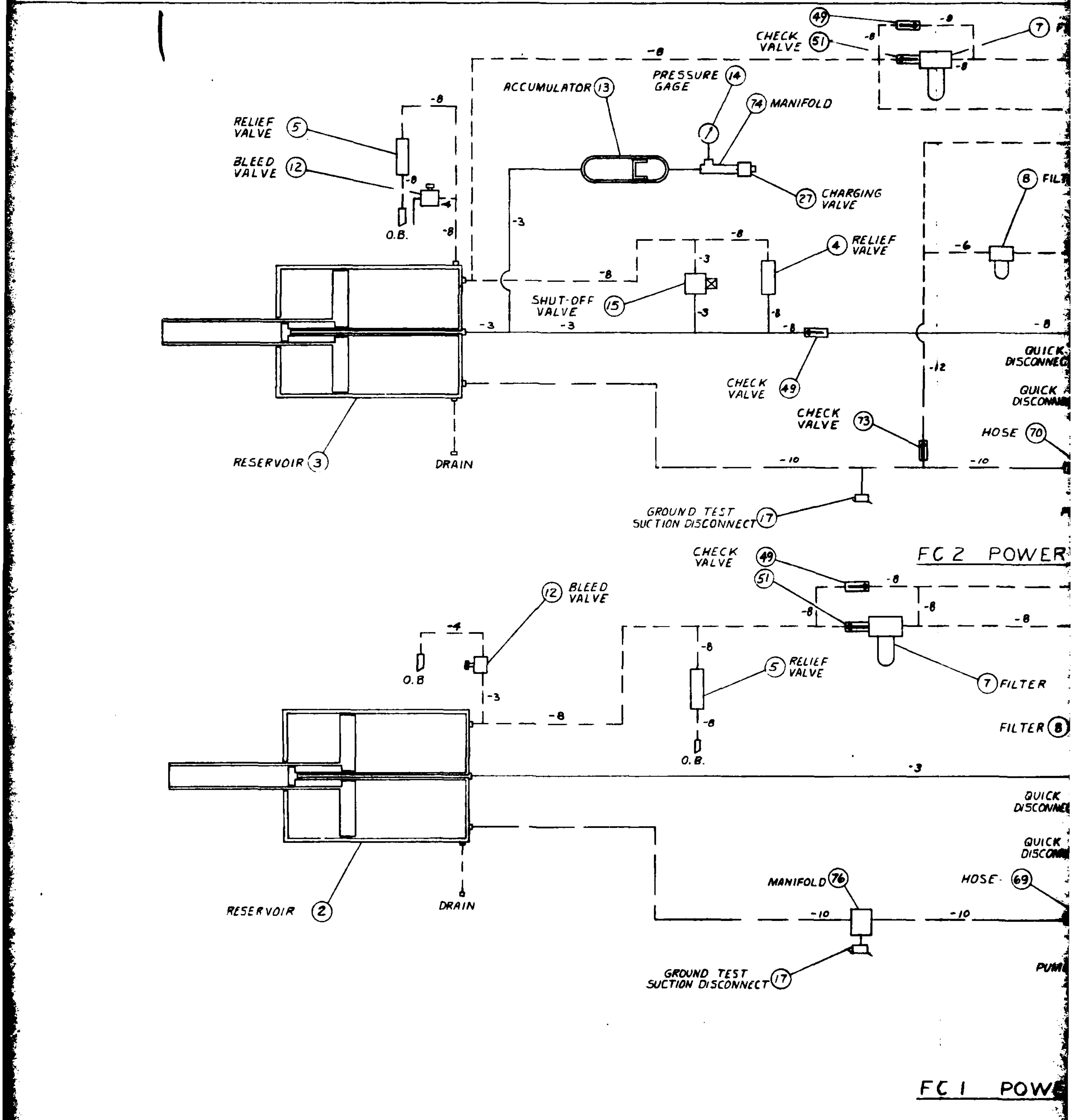
Part No.	Total Number In Test System	Quantity Fabricated In Phase I	LHS Actuator	Type	Mfr.
8696-587100	1	1	Rudder (see Figure 7)	Dual Tandem	NAAD
83-00201	1	1	Speed Brake (see Figure 8)	Single Cylinder	Vought
83-00211	2	1	Unit Horizontal Tail (UHT) (see Figure 9)	Dual Tandem	Vought
83-00221	2	1	Aileron (see Figure 10)	Dual Tandem	Vought
83-00231	3	1	Automatic Flight Cont.Sys.(AFCS) (see Figure 11)	Dual Parallel	Vought
83-00251	1	0	Roll Feel Isolation	Dual Tandem	Vought
83-00261	8	0	Leading Edge Flap	Single Cylinder	Vought
83-00271	2	0	Spoiler/ Deflector	Dual Tandem	Vought

Sperry Vickers P/N 570937, M/N PV3-047-2

FC-1 S/N 346581

FC-2 S/N 348168

FIGURE 4. LHS pump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PRESSURE GAGE 14
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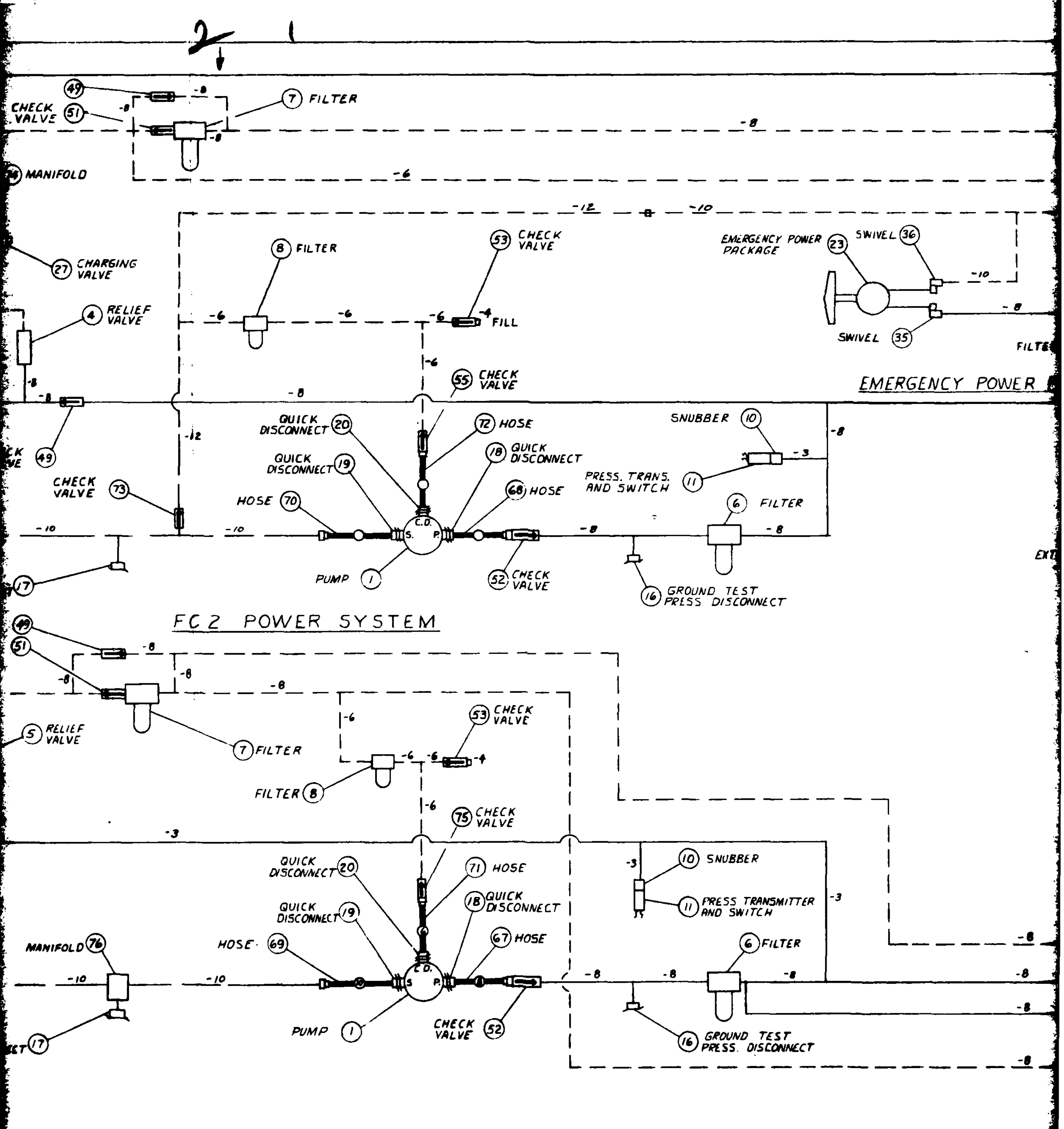

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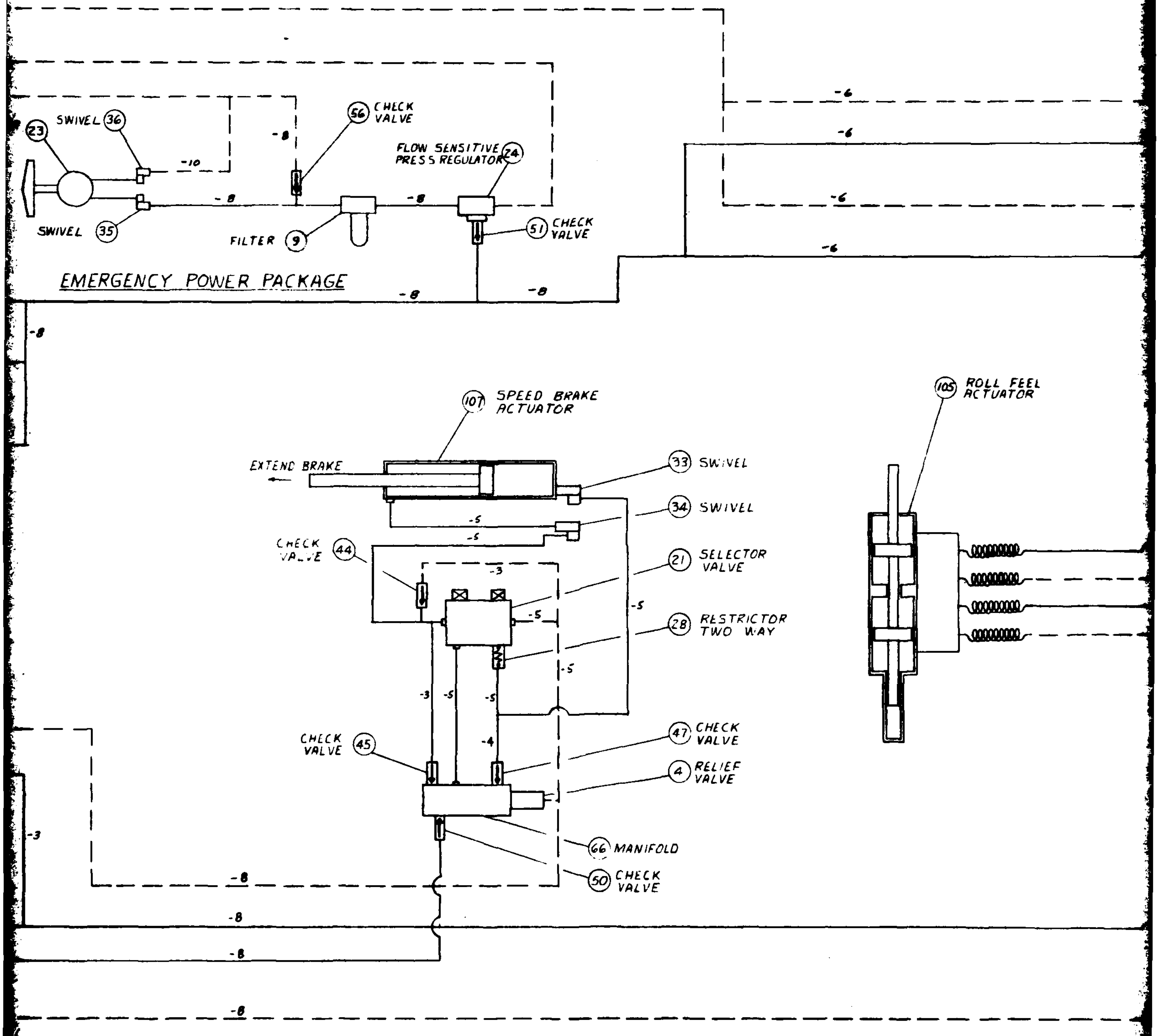

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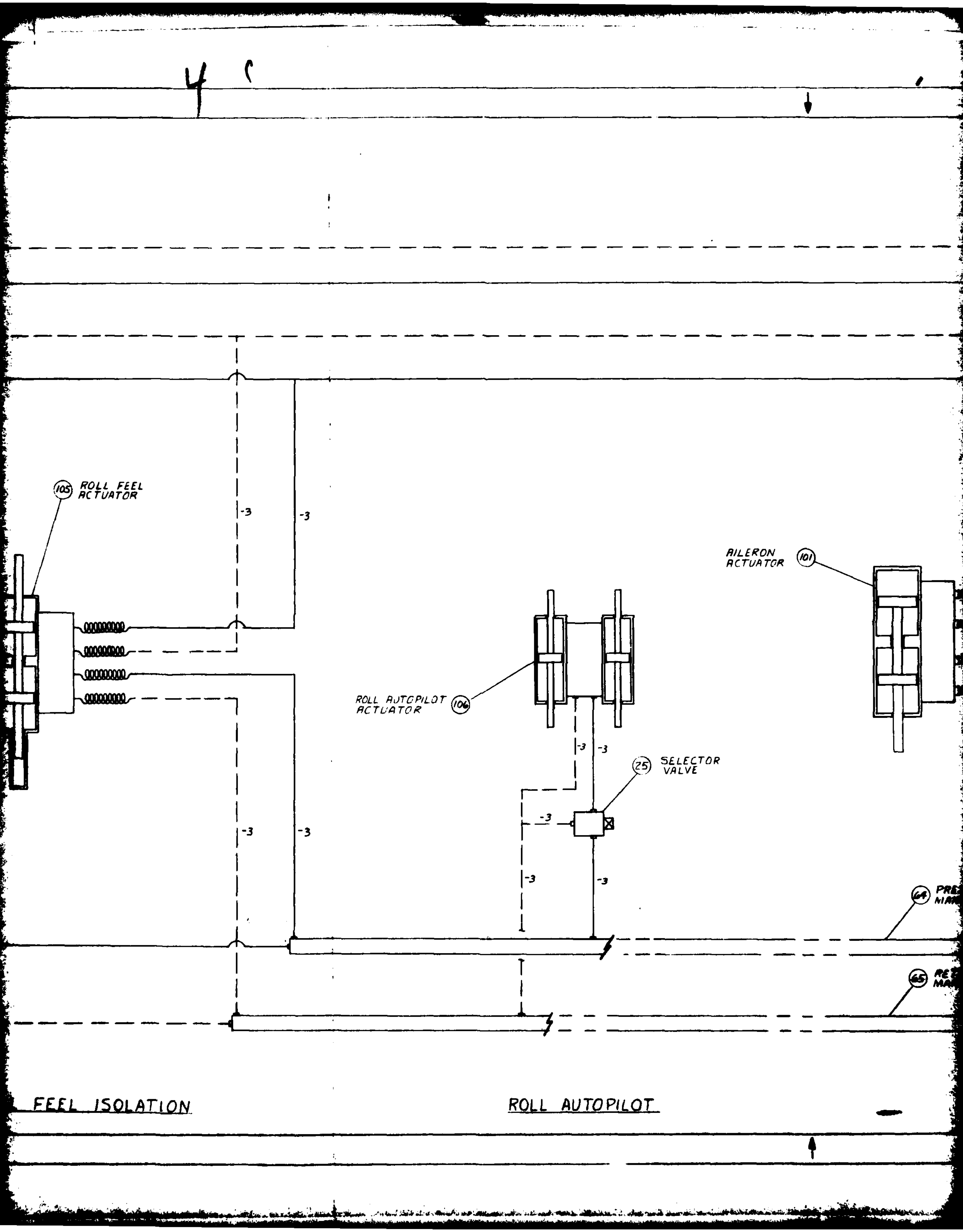

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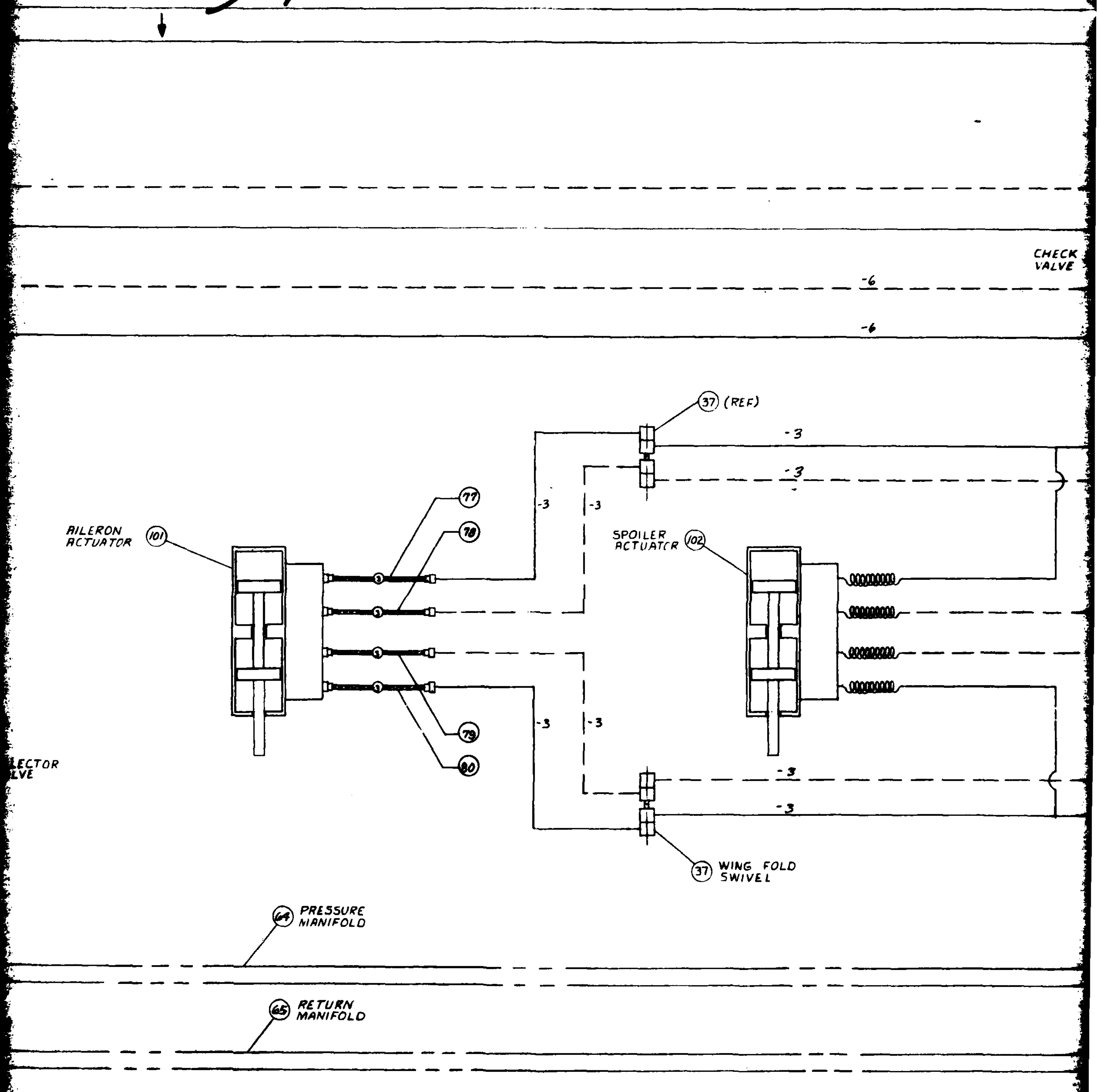

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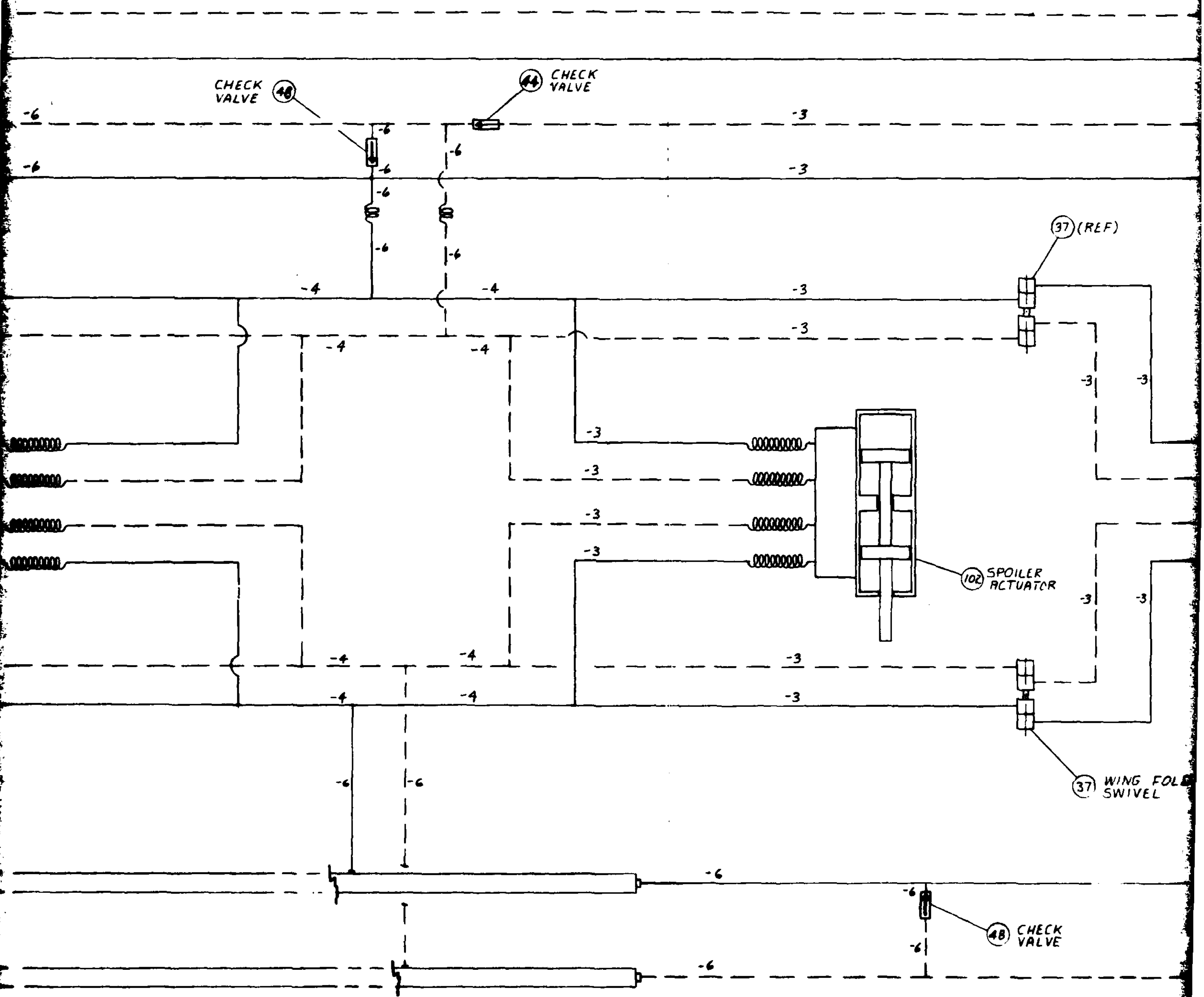

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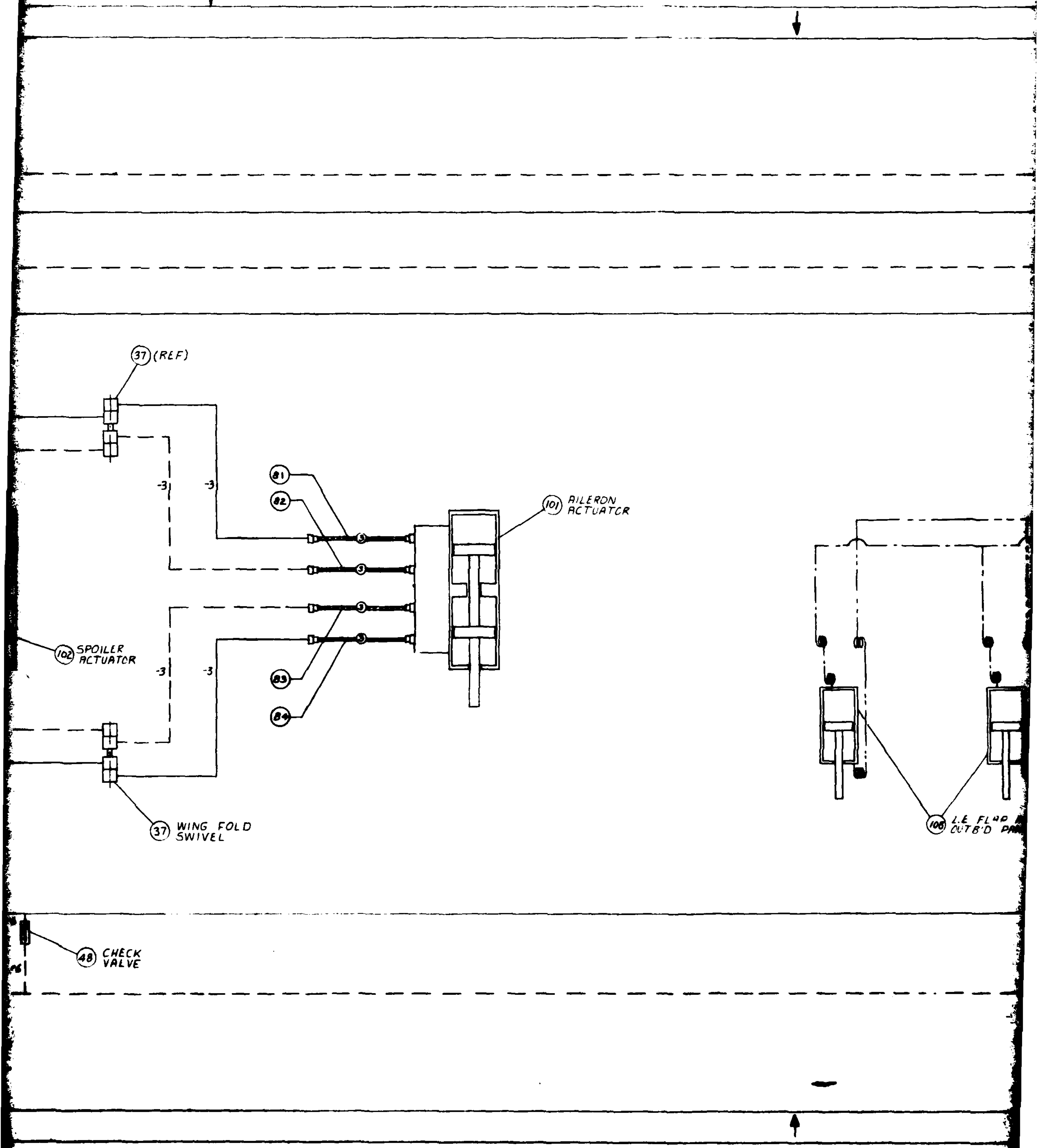
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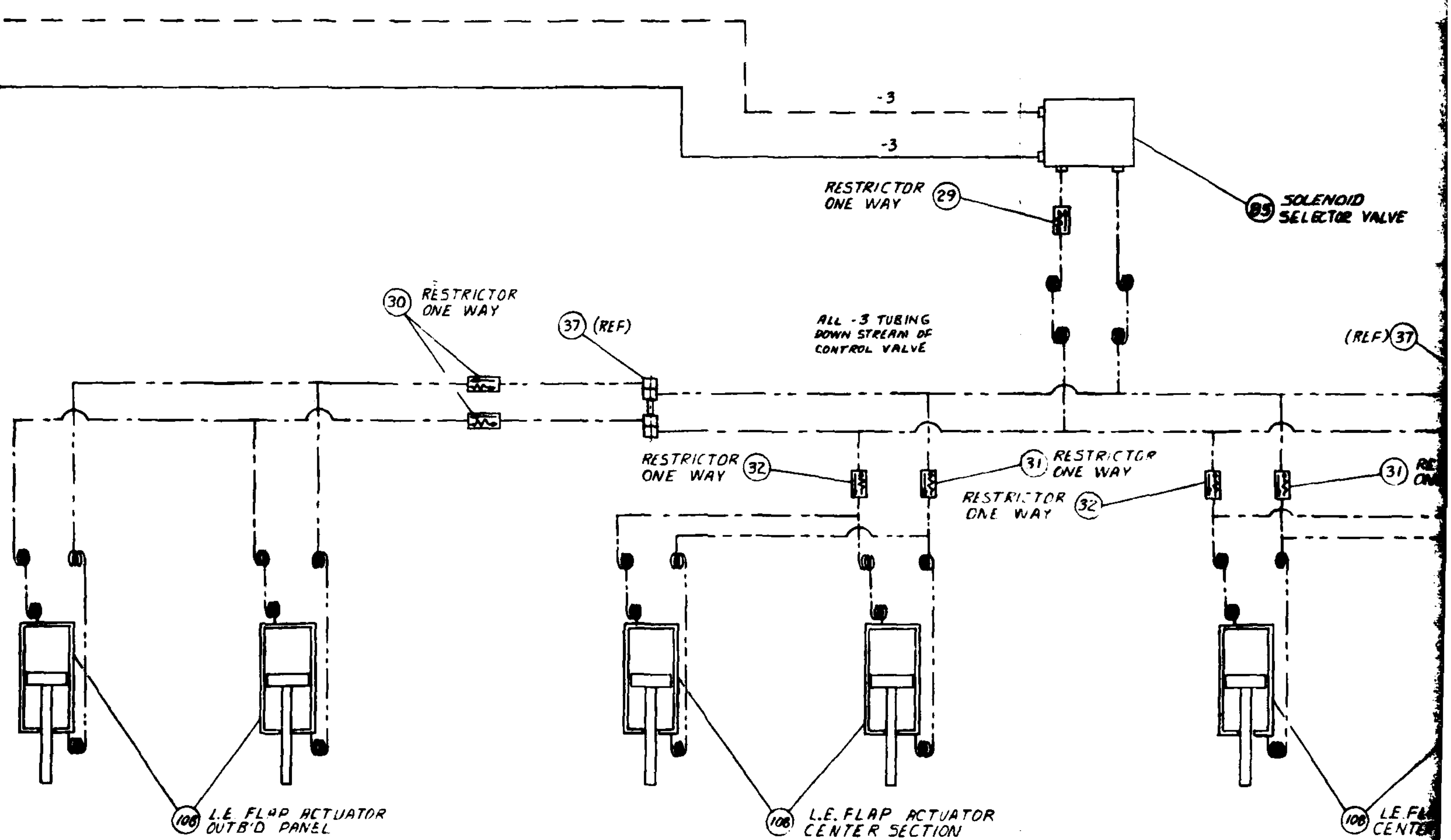
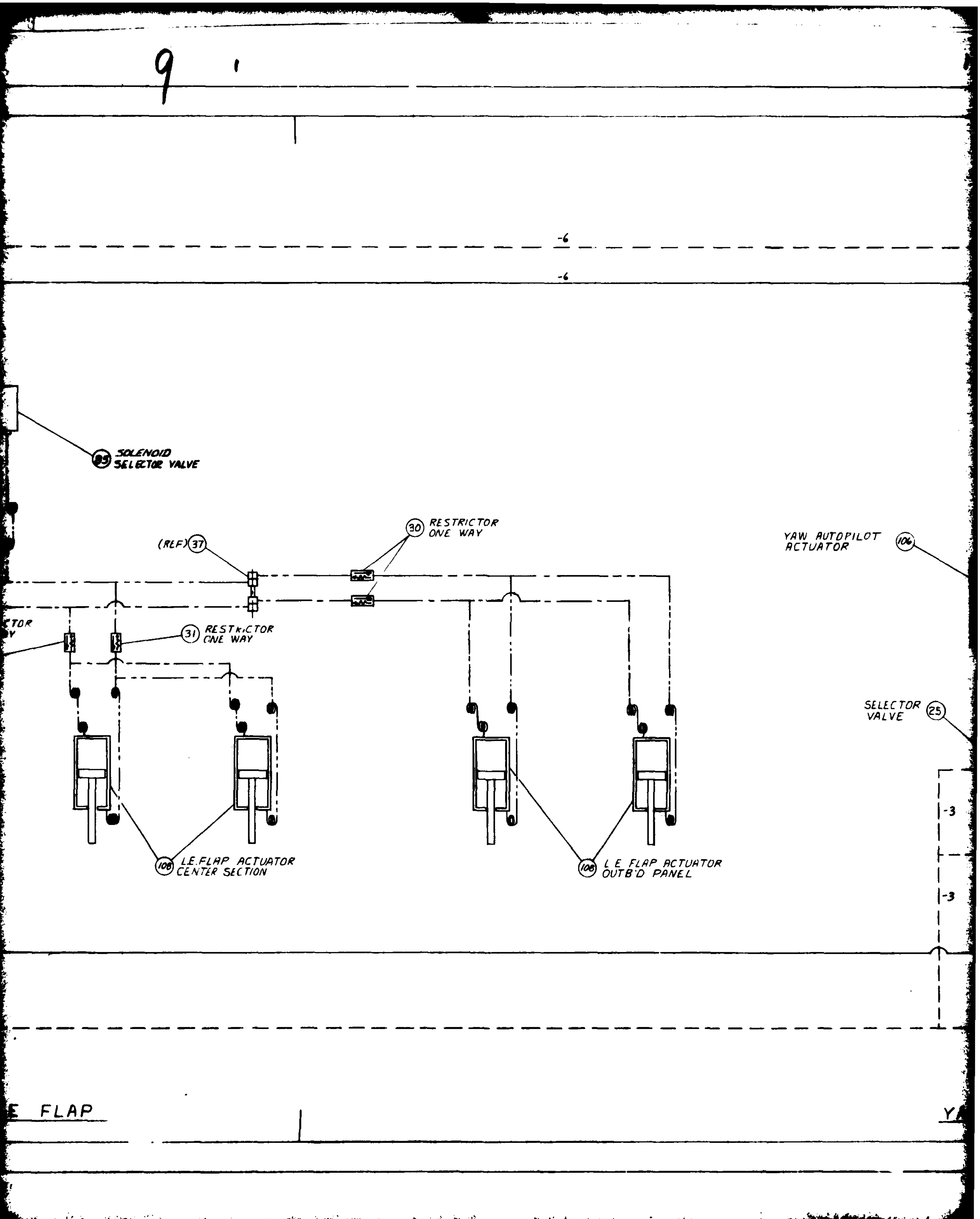
37 WING FOLD SWIVEL
108 L.E. FLAP
OUTB'D
48 CHECK VALVE

8

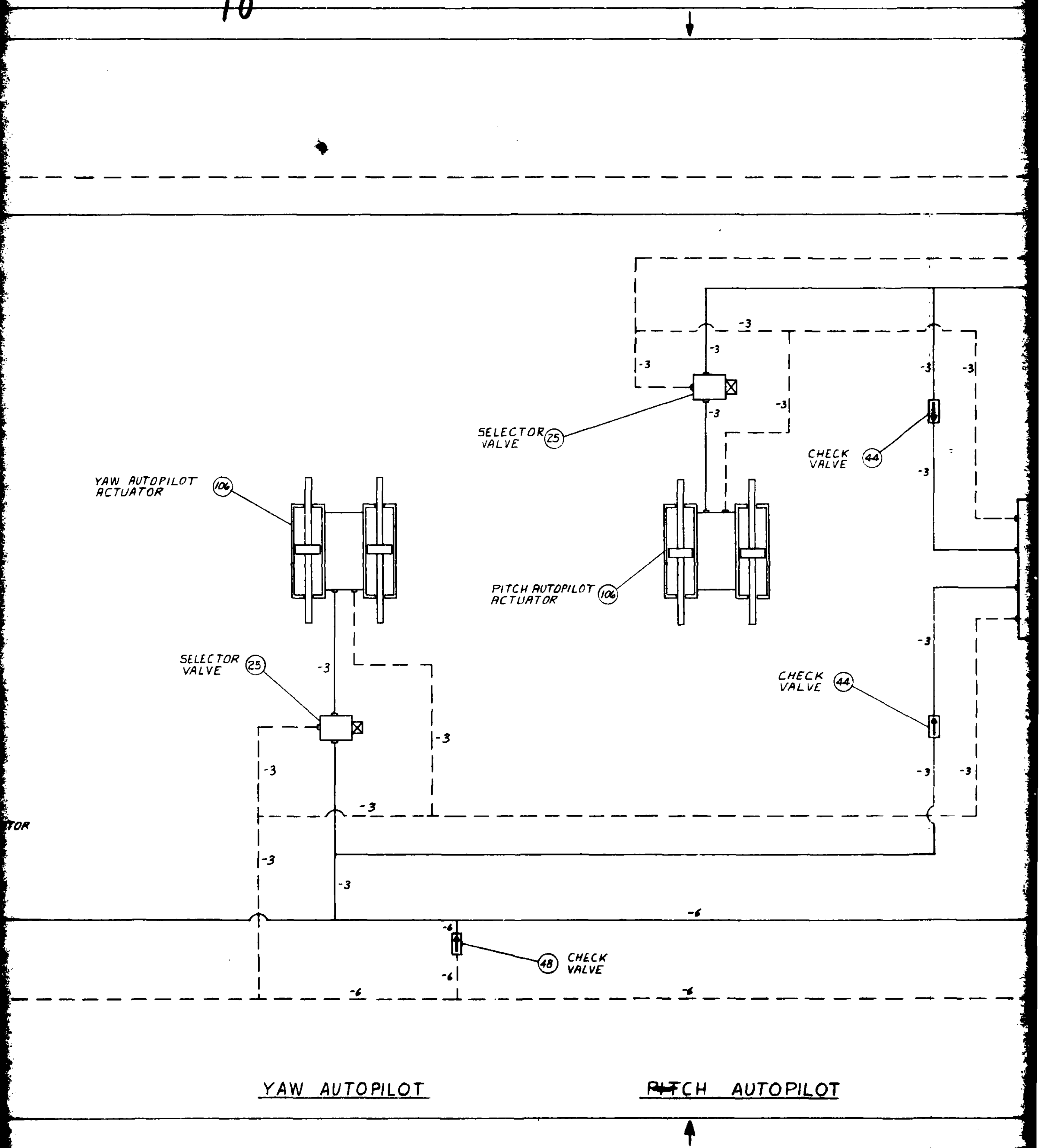


8696-580001		1

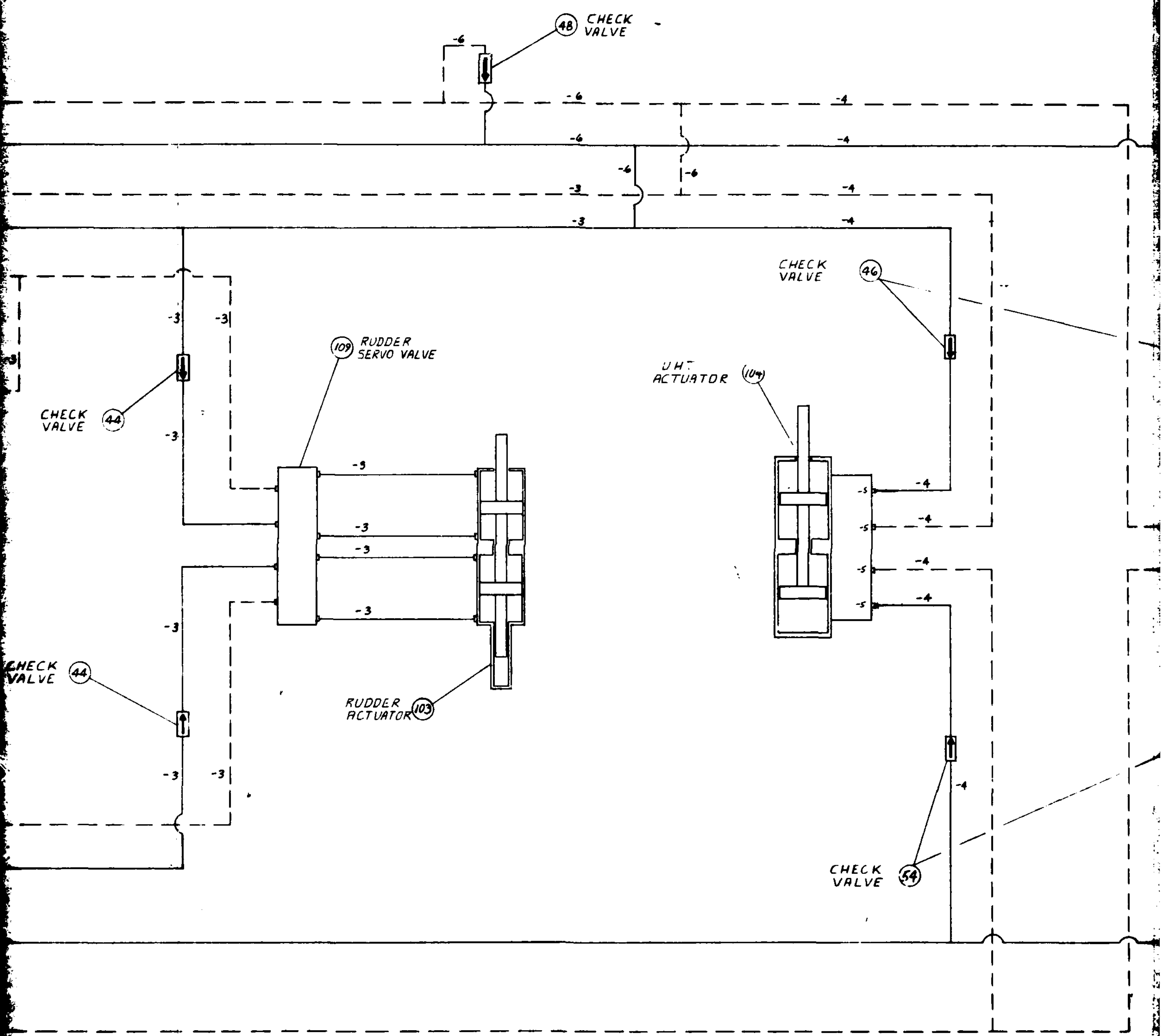
LEADING EDGE FLAP


9
-6
-6
85 SOLENOID SELECTOR VALVE
(REF) 37
30 RESTRICTOR ONE WAY
YAW AUTOPILOT ACTUATOR 106
31 RESTRICTOR ONE WAY
SELECTOR VALVE 25
108 L.E. FLAP ACTUATOR CENTER SECTION
108 L E FLAP ACTUATOR OUTB'D PANEL
-3
-3
FLAP

10'



SELECTOR VALVE 25
CHECK VALVE 44
YAW AUTOPILOT ACTUATOR 106
PITCH AUTOPILOT ACTUATOR 106
SELECTOR VALVE 25
CHECK VALVE 44
CHECK VALVE 48
-3
-6
YAW AUTOPILOT
PITCH AUTOPILOT



PILOT | RUDDER | 8696-580001 | 1 | UNIT HORIZONTAL

12

REVISIONS					
ZONE	LTR	DESCRIPTION	DISPN	DATE	APPROVED
		1. MAY BE REWORKED 2. CANNOT BE REWORKED 3. RECORD CHANGE 4. NOW SHOP PRACTICE 5. PARTS MADE OK			
	A	1. REPLACED LEADING EDGE SWIVELS WITH COILED TUBE (ITEMS 41,42 & 43)	3		
		2. REPLACED WING/FUS. SWIVELS WITH COILED TUBE (ITEMS 38, 39 & 40)	3		
		3. REPLACED LINE EXTENSION UNITS (ITEMS 57 THRU 63) WITH COILED TUBE AND HOSES (ITEMS 77 THRU 84)	3		
		4. DELETED SPEED BRAKE MANUAL UNLOADING VALVE (ITEM 22)	3		
		5. REPLACED MANUALLY OPER. VALVE (ITEM 26) WITH SOLENOID OPER. VALVE (ITEM 85). ADDED ITEM 76.			
		6. REVISED CHECK VALVE CALLOUTS	3		
		7. UPDATED SHT 2 TABLES	3		
		8. ADDED FC1 PUMP CASE DRAIN FILTER			B. HOLLAND 12 DEC. 1980

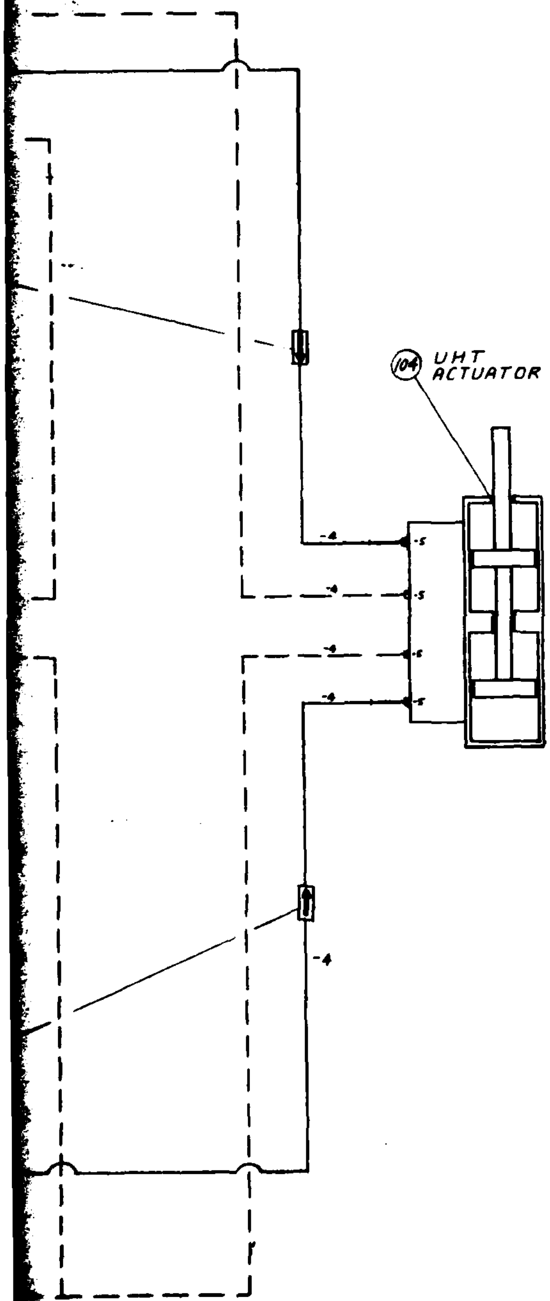


FIGURE 5

HORIZONTAL TAIL

CONTR NO.			Rockwell International Corporation, Columbus Aircraft Division
DWN BY	B. HOLLAND	3-14-79	SCHEMATIC DIAGRAM FC1 & FC2 HYDRAULIC SYSTEM
CHK BY			
APVD	L. PE[illegible]	[illegible]	
	[illegible signature]	12-19-80	
SIZE L	CODE IDENT NO 89372	8696-580001	
SCALE NONE		SHEET 1 OF 2	

8696-580001

8696-580001

ITEM	ZONE	QTY	PART NUMBER DWG. NUMBER	NOMENCLATURE	REMARKS	NEXT ASSEMBLY	ENV. DRAWING PROC. SPEC. TEST SPEC.
1		2	PV3-47-2	PUMP - FC1 & FC2 SYSTEMS	10.0 GPM AT 7700 PSI AND 5900 RPM		HE 281-5015 LHS-8100
2		1	83-00241-	RESERVOIR - FC1	319.4 IN³ MAX SWEPT VOL. BOOTSTRAP TYPE - 98.6 PSI AT 8000 PSI	8696-580016	
3		1	83-00241-	RESERVOIR - FC2	319.4 IN³ MAX SWEPT VOL. BOOTSTRAP TYPE - 98.6 PSI AT 8000 PSI.	8696-580020	
4		2	1257 1258	RELIEF VALVE - FC1 & FC2 SYSTEMS	FC1 / FC2: 10.0 GPM AT 8800 PSID 8200 PSI RESEAT PRESS	8696-580017 8696-580020	LHS-8029
5		2		RELIEF VALVE - RESERVOIR, FC1 & FC2 SYSTEMS		8696-580016 8696-580020	
6		2	AD-A640-83Y1	FILTER - PRESSURE, FC1 & FC2 SYSTEMS	5µ ABS., NON-BYPASS TYPE REPLACEMENT ELEMENT-AC-A640F-5	8696-580016 8696-580020	LHS-8115-1
7		2	M8815/4A-8	FILTER - RETURN, FC1 & FC2 SYSTEMS	5µ ABS., BYPASS TYPE	8696-580016 8696-580020	MIL-F-8815
8		1	M8815/4A-6	FILTER - PUMP BYPASS, FC2 SYSTEM	5µ ABS., BYPASS TYPE	8696-580020	MIL-F-8815
9		1	AD3258-8HV	FILTER - EMERGENCY POWER PACKAGE, FC2 SYSTEM	RATED FLOW - 6 GPM	215-02011	215-32484 205-15-2081 204-15-360
10		2	95239	PRESSURE SNUBBER FC1 & FC2 SYSTEMS		8696-580016 8696-580020	LHS-8024
11		2	18-2143	PRESSURE TRANSMITTER & SWITCH, - FC1 & FC2 SYSTEMS	SWITCH "OPENS" @ 4900 PSI (INCR. PR.) "CLOSES" @ 4000 PSI (DECR. PRESS)	8696-580016 8696-580020	LHS-8026
12		2	4D121	BLEED VALVE, FC1 & FC2 SYSTEMS		8696-580016 8696-580020	—
13		1	3321471	ACCUMULATOR - FC2 SYSTEM	9 IN³ SWEPT OIL VOLUME 2 IN³ MIN. GAS VOLUME	8696-580020	HE-282-5001 LHS-8011
14		1	1218-63-1	PRESSURE GAGE, FC2 SYSTEM		8696-580017	LHS-8122-1
15		1		SHUT-OFF VALVE, SOLENOID OPERATED FC2, PRESS. DUMP		8696-580020	HE-284-5059 LHS-8037
16		2	AE80942H	QUICK DISCONNECT, PRESS. GROUND-COUPLING HALF AND DUST CAP, FC1 & FC2		8696-580016 8696-580020	LHS-8028
17		2	3018-54-12D 01553-57-12D	QUICK DISCONNECT, SUCTION GROUND-COUPLING HALF AND DUST CAP, FC1 & FC2		8696-580016 8696-580020	210-32587 205-10-2074
18		2 2	AE80943H AE80944H	QUICK DISC. PUMP PRESS. HOSE HALF & BULKHEAD HALF, FC1 & FC2	HOSE HALF W/DUST CAP PUMP HALF W/DUST CAP	8696-580020	LHS-8028
19		2 2	AE94951J AE94952J	QUICK DISC. PUMP SUCTION, HOSE HALF & BULKHEAD HALF, FC1 & FC2	HOSE HALF PUMP HALF	8696-580020	LHS-8028
20		2 2	AE94951G AE94952G	QUICK DISC. PUMP C.DR., HOSE HALF & BULKHEAD HALF, FC1 & FC2	HOSE HALF PUMP HALF	8696-580020	218-42305 205-18-2005 204-18-28
21		1	3321472	SELECTOR VALVE SOLENOID OPERATED FC1, SPEED BRAKE	4.5 GPM @ 50 PSID	8696-580017	HE 284-5061 LHS-8037
~~22~~		~~1~~		~~VALVE, UNLOADING, MANUALLY OPERATED: FC1, SPEED BRAKE~~			
23		1	953812-4-1	EMERGENCY POWER PACKAGE, FC2		218-02011	216-27220 205-18-5002 204-16-71
24		1	EA50002-24	FLOW SENSITIVE PRESS. REGULATOR EMERGENCY POWER PACKAGE, FC2	INCLUDES RELIEF VALVE	8696-580020	215-22131 205-15-2040 204-15-156
25		3	3321473	SELECTOR VALVE, SOLENOID OPERATED - SAS, FC1 & FC2	1.4 GPM @ 50 PSID	8696-580022	HE 284-5060 LHS-8037
~~26~~		~~1~~		~~SELECTOR VALVE, MANUALLY OPERATED L.E. FLAP, FC2~~			

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NEXT ASSEMBLY	ENV. DRAWING PROC. SPEC. TEST SPEC.	VENDOR AND (CODE IDENT.)	SOURCE	
	HE 281-5015 LHS-8100	SPERRY-VICKERS JACKSON, MISS (62983)	NEW PURCHASE	
8696-580016		VOUGHT CORP. DALLAS, TEXAS (80378)		
8696-580020		VOUGHT CORP. DALLAS, TEXAS (80378)		
8696-580017 8696-580020	LHS-8029	PNEUDRAULICS MONTCLAIR, CA. (06177)	NEW PURCHASE	
8696-580016 8696-580020				
8696-580016 8696-580020	LHS-8115-1	AIRCRAFT POROUS MEDIA NORTH PINELLAS PK., FL (18350)	NEW PURCHASE	
8696-580016 8696-580020	MIL-F-8815	SEE QPL		
8696-580020	MIL-F-8815	SEE QPL		
215-02011	215-32484 205-15-2081 204-15-360	AIRCRAFT POROUS MEDIA INC. GLEN COVE N.Y. (01414)	A-7 ASSETS	
8696-580016 8696-580020	LHS-8024	GAR KENYON NEW HAVEN, CT (26044)	NEW PURCHASE	
8696-580016 8696-580020	LHS-8026	BENDIX CORP, COURTER INC. BOYNE CITY MICH. (96774)	NEW PURCHASE	
8696-580016 8696-580020	—	ALLEN AIRCRAFT PROD. RAVENNA, OHIO (82829)		
8696-580020	HE-282-5001 LHS-8011	BENDIX ELECTRODYNAMICS N. HOLLYWOOD CA.	NEW PURCHASE	
8696-580017	LHS-8122-1	QED/INC. SANTA ANNA, CA. (24708)	NEW PURCHASE	
8696-580020	HE-284-5059 LHS-8037		NEW PURCHASE	
8696-580016 8696-580020	LHS-8028	AEROQUIP CORP JACKSON, MICH. (00624)	NEW PURCHASE	
8696-580016 8696-580020	210-32587 205-10-2074	AEROQUIP CORP. JACKSON, MICH. (00624)	A-7 ASSETS	
8696-580020	LHS-8028	AEROQUIP CORP. JACKSON, MICH. (00624)	NEW PURCHASE	
8696-580020	LHS-8028	AEROQUIP CORP. JACKSON MICH. (00624)	A-7 ASSETS	
8696-580020	218-42305 205-18-2005 204-18-28	AEROQUIP CORP. JACKSON MICH. (00624)	A-7 ASSETS	
8696-580017	HE 284-5061 LHS-8037	BENDIX ELECTRODYNAMICS N. HOLLYWOOD, CA.	NEW PURCHASE	
218-02011	216-27220 205-18-5002 204-16-71	GARRETT AIR RESEARCH L.A. CALIF. (70210)	A-7 ASSETS	
8696-580020	215-22131 205-15-2040 204-15-156	SPERRY-VICKERS JACKSON MISS. (62983)	A-7 ASSETS	
8696-580022	HE 284-5060 LHS-8037	BENDIX ELECTRODYNAMICS N. HOLLYWOOD, CA.	NEW PURCHASE	

ITEM	ZONE	QTY	PART NUMBER DWG. NUMBER	NOMENCLATURE
27		1		CHARGING VALVE, PNEUMATIC FC2, ACCUMULATOR
28		1	RLFX0380250A	RESTRICTOR- TWO WAY, SPEED BRAKE, FC1
29		1		RESTRICTOR-ONE WAY, L.E. FLAP, FC2
30		4		RESTRICTOR-ONE WAY, L.E. FLAP OUTB'D PANEL, FC2
31		2		RESTRICTOR - ONE WAY, L.E FLAP, INB'D PANEL, RETRACT, FC2
32		2		RESTRICTOR, ONE WAY, L.E. FLAP, INB'D PANEL, EXTEND, FC 2
33		1		SWIVEL JOINT- SPEED BRAKE EXTEND, FC1
34		1		SWIVEL JOINT-SPEED BRAKE RETRACT, FC1
35		1	141950	SWIVEL JOINT-EMER. POWER PACKAGE (RAT) FC2
36		1	141955	SWIVEL JOINT-EMER. POWER PAKAGE (RAT) FC2
37		2		SWIVEL JOINT- WINGFOLD, FC1 & FC2
~~38~~		~~2~~		~~SWIVEL JOINT-WING CONNECTION, FC 2 PRESS. & RETURN~~
~~39~~		~~2~~		~~SWIVEL JOINT-L.E. FLAP WING CONNECT, FC 2~~
~~40~~		~~2~~		~~SWIVEL JOINT-L.E. FLAP WING CONNECT, FC2~~
~~41~~		~~8~~		~~SWIVEL JOINT-L.E. FLAP ACTR. CONNECT, OUTB'D PANEL, FC2~~
~~42~~		~~8~~		~~SWIVEL JOINT-L.E. FLAP ACTR. CONNECT, OUTB'D PANEL, FC2~~
~~43~~		~~8~~		~~SWIVEL JOINT-L.E. FLAP ACTR. CONNECT, INBD. PANEL, FC2~~
44		4	95202-1	CHECK VALVE, PRESSURE & RETURN
45		1	95200-1	CHECK VALVE, PRESSURE & RETURN
46		2	95202-2	CHECK VALVE, PRESSURE & RETURN
47		1	95200-2	CHECK VALVE, PRESSURE & RETURN
48		4	95202-4	CHECK VALVE, PRESSURE & RETURN
49		3	95202-5	CHECK VALVE, PRESSURE & RETURN
50		1	95200-5	CHECK VALVE, PRESSURE & RETURN
51		3	952xx-5	CHECK VALVE, PRESSURE & RETURN
52		2	95201-5	CHECK VALVE, PRESSURE & RETURN

3 1

ART NUMBER / NG. NUMBER	NOMENCLATURE	REMARKS	NEXT ASSEMBLY	ENV. DRAWING PROC. SPEC. TEST SPEC	VENDOR AND (CODE IDENT.)	SOURCE	
	CHARGING VALVE, PNEUMATIC FC2, ACCUMULATOR						
FX0380250A	RESTRICTOR- TWO WAY, SPEED BRAKE, FC1	4.0 GPM AT 7800 PSID TYPE IIB		LHS-8131-1	LEE CO. WESTBROOK CT. (92555)	NEW PURCHASE	
	RESTRICTOR-ONE WAY, L.E. FLAP, FC2	TYPE IB		LHS-8031			
	RESTRICTOR-ONE WAY, L.E. FLAP OUTB'D PANEL, FC2	TYPE IA		LHS-8031			
	RESTRICTOR - ONE WAY, L.E. FLAP, INB'D PANEL, RETRACT, FC2	TYPE I A		LHS-8031			
	RESTRICTOR, ONE WAY, L.E. FLAP, INB'D PANEL, EXTEND, FC 2	[illegible] IA		LHS-8031			
	SWIVEL JOINT- SPEED BRAKE EXTEND, FC1			ME278-5001-0003 LHS-8038			
	SWIVEL JOINT-SPEED BRAKE RETRACT, FC1			ME278-5001-0001 LHS-8038			
141950	SWIVEL JOINT-EMER. POWER PACKAGE (RAT) FC2	PRESSURE LINE (3000 PSI)		215-22307 205-15-2036 204-15-143	DUMONT ENGRG CO. LONG BEACH CALIF (97928)	A-7 ASSETS	
141955	SWIVEL JOINT-EMER. POWER PAKAGE (RAT) FC2	SUCTION LINE		215-22307 205-15-2036 204-15-143	DUMONT ENGRG. CO. LONG BEACH CALIF. (97928)	A-7 ASSETS	
	SWIVEL JOINT- WINGFOLD, FC1 & FC2	FC1 & FC2 PRESS. & RETURN, L.E. FLAP EXTEND & RETRACT		LHS-8038			
	~~SWIVEL JOINT-WING CONNECTION, FC 2 PRESS. & RETURN~~			~~LHS-8038~~			
	~~SWIVEL JOINT-L.E. FLAP WING CONNECT, FC2~~	~~FUSELAGE SIDE~~		~~LHS-8038~~			
	~~SWIVEL JOINT-L.E. FLAP WING CONNECT, FC2~~	~~WING SIDE~~		~~LHS-8038~~			
	~~SWIVEL JOINT-L.E. FLAP ACTR. CONNECT, OUTB'D PANEL, FC2~~	~~WING SIDE~~		~~LHS-8038~~			
	~~SWIVEL JOINT-L.E. FLAP ACTR. CONNECT, OUTB'D PANEL, FC2~~	~~ACTUATOR SIDE~~		~~LHS-8038~~			
	~~SWIVEL JOINT-L.E. FLAP ACTR. CONNECT, INBD. PANEL, FC2~~	~~WING SIDE~~		~~LHS-8038~~			
95202-1	CHECK VALVE, PRESSURE & RETURN	TYPE I, -3 SIZE RUDDER SP. BRAKE, FLAP RETURN	8696-580017 8696-580021 8696-580011	LHS-8114-1	GAR-KENYON NEW HAVEN, CT. (26044)	NEW PURCHASE	
95200-1	CHECK VALVE, PRESSURE & RETURN	TYPE IIB-3 SIZE SPEED BRAKE	8696-580017	LHS-8114-1	GAR-KENYON NEW HAVEN, CT. (26044)	NEW PURCHASE	
95202-2	CHECK VALVE, PRESSURE & RETURN	TYPE I, -4 SIZE UHT	8696-580020	LHS-8114-1	GAR-KENYON NEW HAVEN, CT. (26044)	NEW PURCHASE	
95200-2	CHECK VALVE, PRESSURE & RETURN	TYPE IIB-4 SIZE SP. BRAKE	8696-580017	LHS-8114-1	GAR-KENYON NEW HAVEN, CT. (26044)	NEW PURCHASE	
95202-4	CHECK VALVE, PRESSURE & RETURN	TYPE I, -6 SIZE FC1 & FC2 RUN AROUND & WING RUN AROUND	8696-580020 8696-580022	LHS-8114-1	GAR-KENYON NEW HAVEN, CT. (26044)	NEW PURCHASE	
95202-5	CHECK VALVE, PRESSURE & RETURN	TYPE I, -8 SIZE ACCUM ISOL., FC1 & FC2 FILTER RUNAROUND	8696-580020 8696-580016	LHS-8114-1	GAR-KENYON NEW HAVEN, CT. (26044)	NEW PURCHASE	
95200-5	CHECK VALVE, PRESSURE & RETURN	TYPE IIB, -8 SIZE SP. BRAKE	8696-580017	LHS-8114-1	GAR-KENYON NEW HAVEN CT. (26044)	NEW PURCHASE	
952xx-5	CHECK VALVE, PRESSURE & RETURN	TYPE IIA, -8 SIZE RAT REGULATOR OUTLET, FC1 & FC2 RETURN FILTER	8696-580020 8696-580016	LHS-8114-1	GAR-KENYON NEW HAVEN CT. (26044)	NEW PURCHASE	
95201-5	CHECK VALVE, PRESSURE & RETURN	TYPE IIB -8 SIZE PUMP PRESS.	8696-580020	LHS-8114-1	GAR-KENYON NEW HAVEN CT. (26044)	NEW PURCHASE	

4 1

	SOURCE		ITEM	ZONE	QTY	PART NUMBER DWG. NUMBER	NOMENCLATURE	REMARKS	NEXT ASSEMBLY	ENV. DRAWING PROC. SPEC. TEST SPEC.
			53		2		CHECK VALVE, RETURN	-4/-6 SIZE, MS/DYN BLKHD-SYS. FILL, FC1 & FC2	8696-580016 8696-580020	
	NEW PURCHASE		54		2	95201-2	CHECK VALVE PRESSURE & RETURN	TYPE IIIB, -4 SIZE UHT PRESS (FC1)	8696-580020	LHS-8114-1
			55		1		CHECK VALVE, RETURN	TYPE IIIA -6 SIZE CASE DRAIN, FC2	8696-580020	LHS-8114-1
			56		1	CVC-4124-8	CHECK VALVE, RETURN	-8 SIZE RAT BYPASS	218-02011 LTV	
			~~57~~		~~2~~		~~EXTENSION UNIT - ROLL FEEL, FC2 PRESS & RETURN~~			
			~~58~~		~~1~~		~~EXTENSION UNIT ROLL FEEL, FC1 RETURN~~			
			~~59~~		~~1~~		~~EXTENSION UNIT ROLL FEEL, FC1 PRESS.~~			
			~~60~~		~~4~~		~~EXTENSION UNIT, SPOILER, FC1 PRESS. & RETURN~~			
CO.	A-7 ASSETS		~~61~~		~~4~~		~~EXTENSION UNIT SPOILER, FC2 PRESS. & RETURN~~			
CO. F.	A-7 ASSETS		~~62~~		~~6~~		~~EXTENSION UNIT AILERON, FC1 PRESS. FC1 & FC2 RETURN~~			
			~~63~~		~~2~~		~~EXTENSION UNIT AILERON, FC2 PRESS~~			
			64		1	8696-581002	MANIFOLD - FC1 PRESS.		8696-580022	
			65		1	8696-58003	MANIFOLD - FC1 RETURN		8696-580022	
			66		1	8696-581201	MANIFOLD - FC1 RELIEF VALVE		8696-580017	
			67		1		HOSE ASSEMBLY-PUMP PRESSURE, FC1	-8 SIZE	8696-580020	LHS-8018
			68		1		HOSE ASSEMBLY-PUMP PRESSURE, FC2	-8 SIZE	8696-580020	LHS-8018
			69		1		HOSE ASSEMBLY-PUMP SUCTION, FC1	-10 SIZE	8696-580020	
	NEW PURCHASE		70		1		HOSE ASSEMBLY-PUMP SUCTION, FC2	-10 SIZE	8696-580020	
	NEW PURCHASE		71		1		HOSE ASSEMBLY-PUMP CASE DRAIN, FC1	-6 SIZE	8696-580020	
	NEW PURCHASE		72		1		HOSE ASSEMBLY-PUMP CASE DRAIN, FC2	-6 SIZE	8696-580020	
	NEW PURCHASE		73		1	(4C [illegible]	CHECK VALVE, RETURN	-10/-12 SIZE, RAT SUCTION	8696-580020	
	NEW PURCHASE		74		1	[illegible]	MANIFOLD - FC2 ACCUMULATOR		8696-580017	
	NEW PURCHASE		75		1	95201-4	CHECK VALVE, PRESSURE & RETURN	TYPE IIIB, -6 SIZE, FC1 CASE DRAIN	8696-580020	LHS-8114-1
	NEW PURCHASE		76		1	8696-581001	MANIFOLD, FC1 SUCTION DISC.		8696-580016	
	NEW PURCHASE		77		1		HOSE ASSEMBLY - AILERON PRESSURE, FC2	-3 SIZE		LHS-8018
	NEW PURCHASE		78		1		HOSE ASSEMBLY - AILERON RETURN, FC2	-3 SIZE		LHS-8018

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NEXT ASSEMBLY	ENV. DRAWING PROC. SPEC. TEST SPEC.	VENDOR AND CODE IDENT.	SOURCE	
8696-580016 8696-580020				
8696-580020	LHS-8114-1	GAR-KENYON NEW HAVEN, CT. (26044)	NEW PURCHASE	
8696-580020	LHS-814-1	GAR-KENYON NEW HAVEN, CT. (26044)	NEW PURCHASE	
218-02011 LTV				
8696-580022		ROCKWELL		
8696-580022		ROCKWELL		
8696-580017		ROCKWELL		
8696-580020	LHS-8018			
8696-580020	LHS-8018			
8696-580020				
8696-580020				
8696-580020				
8696-580020				
8696-580020				
8696-580017		VOUGHT CORP. DALLAS TEXAS (80378)		
8696-580020	LHS-8114-1	GAR KENYON NEW HAVEN, CT. (26044)		
8696-580016		ROCKWELL		
	LHS-8018			
	LHS-8018			

ITEM	ZONE	QTY	PART NUMBER DWG NUMBER	NOMENCLATURE	
79		1		HOSE ASSEMBLY - AILERON RETURN, FC1	-3 SIZE
80		1		HOSE ASSEMBLY - AILERON PRESSURE, FC1	-3 SIZE
81		1		HOSE-ASSEMBLY - AILERON PRESSURE, FC2	-3 SIZE
82		1		HOSE ASSEMBLY - AILERON RETURN, FC2	-3 SIZE
83		1		HOSE ASSEMBLY - AILERON RETURN, FC1	-3 SIZE
84		1		HOSE ASSEMBLY - AILERON PRESSURE, FC1	-3 SIZE
85		1		SELECTOR VALVE-SOLENOID OPERATED, L.E. FLAP	2.6 GPM

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NOMENCLATURE	REMARKS	NEXT ASSEMBLY	ENV. DRAWING PROC. SPEC TEST SPEC	VENDOR AND CODE IDENT.	SOURCE	
HOSE ASSEMBLY - AILERON RETURN, FC1	-3 SIZE		LHS-8018			
HOSE ASSEMBLY - AILERON PRESSURE, FC1	-3 SIZE		LHS-8018			
HOSE-ASSEMBLY - AILERON PRESSURE, FC2	-3 SIZE		LHS-8018			
HOSE ASSEMBLY - AILERON RETURN, FC2	-3 SIZE		LHS-8018			
HOSE ASSEMBLY - AILERON RETURN, FC1	-3 SIZE		LHS-8018			
HOSE ASSEMBLY - AILERON PRESSURE, FC1	-3 SIZE		LHS-8018			
SELECTOR VALVE-SOLENOID OPERATED, L.E. FLAP	2.6 GPM @ 50 PSID		HE LHS-8037			

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ITEM	ZONE	QTY	PART NUMBER TEST SPEC. PROC. SPEC.	NOMENCLATURE	NEXT ASSEMBLY	VENDOR AND (CODE IDENT.)	DISPLACEMENT CU. IN. EXTEND	DISPLACEMENT CU. IN. RETRACT	STROKE INCHES TOTAL	STROKE INCHES WORK
101		2	83-00221	AILERON ACTUATOR		VOUGHT CORP. DALLAS, TEXAS (80378)	(UP) 5.98	(DN) 3.78	5.30	5.00
102		2	83-00271	SPOILER ACTUATOR		VOUGHT CORP. DALLAS, TEXAS (80378)	(O) 4.45	(C) 2.81	5.30	3.7
103		1	8696-587100	RUDDER ACTUATOR		ROCKWELL INTERNATIONAL CORP. COLUMBUS, OHIO (89372)	4.08	4.08	3.20	2.9
104		2	83-00211	UNIT HORIZONTAL TAIL ACTUATOR		VOUGHT CORP. DALLAS, TEXAS (80378)	(TED) 38.90	(TEU) 27.06	6.58	5.7
105		1	83-00251	ROLL FEEL ISOLATING ACTUATOR		VOUGHT CORP. DALLAS, TEXAS (80378)	.78	.78	1.88	1.6
106		3	83-00231	AUTOPILOT ACTUATOR ROLL, YAW, PITCH		VOUGHT CORP. DALLAS, TEXAS (80378)				
107		1	83-00201	SPEED BRAKE ACTUATOR		VOUGHT CORP. DALLAS, TEXAS (80378)	107.34	28.20	19.94	19.9
108		8	83-00261	LEADING EDGE FLAP ACTUATOR		VOUGHT CORP. DALLAS, TEXAS (80378) OUTER / CENTER	1.48 / 1.64	1.01 / 1.11	.926 / 1.026	.92 / 1.0
109		1	8696-587150	RUDDER SERVO VALVE		ROCKWELL INTERNATIONAL CORP. COLUMBUS. OHIO (89372)				±.06

URCE

8696-580001

8

~~D~~ T.)	DISPLACEMENT CU. IN.		STROKE INCHES		EFFECTIVE PISTON AREA SQ. IN.				PISTON DIA. INCHES		ROD DIA INCHES			THRUST LBS. AT	NO LOAD RATE		MAX FLOW-GPM NO LOAD	
	EXTEND	RETRACT	TOTAL	WORKING	A_1	A_2	A_3	A_4	P_{12}	P_{34}	R_1	R_{23}	R_4	8000 PSI	[illegible]/SEC	IN/SEC	FC1	FC2
RP. XAS	(UP) 5.98	(DN) 3.78	5.30	5.00	.672	.425	.524	.330	.925	.991	-	.561	.749	9568 E 6040 R	100	10.4	1.81 E 1.14 R	1.41 E .81 R
RP. AS	(O) 4.45	(C) 2.81	5.30	3.72	.672	.425	.524	.330	.925	.991	-	.561	.749	9568 E 6040 R	200	12.4	2.16 E 1.37 R	1.69 E 1.06 R
ERNATIONAL US, OHIO	4.08	4.08	3.20	2.94	.694	.694	.694	.694	1.241	1.241	.810	.810	.810	11, 104	93.7	5.74	1.04	1.04
RP. AS	(TED) 38.90	(TEU) 27.06	6.58	5.72	3.51	2.41	3.29	2.32	2.115	2.365	-	1.185	1.623	54,400 E 37,840 R	25	4.35	3.97 E 2.73 R	3.70 E 2.63 R
RP. XAS	.78	.78	1.88	1.68	.233	.233	.233	.233	.925	.925	.748	.748	.748	1864	–	5.25	.318	.318
RP. XAS					.32	.32	–	–	.991	–	.748	.748	-				.858 .515	.537
ORP. EXAS	107.34	28.20	19.94	19.94	5.383	1.414	-	-	2.618	–	-	2.248	-	43064 E 11312 R	–	2.86	3.98 E 1.05 R	
ORP. OUTBD EXAS	1.48	1.01	.926	.926	1.602	1.086	–	–	1.428	–	–	.810	–	12816 E 8688 R				
CENTER	1.64	1.11	1.026	1.026	1.602	1.086	–	–	1.428	–	–	.810	–					
ERNATIONAL US. OHIO				±.06														

9

FIGURE 5 (CONT.)

8696-580001

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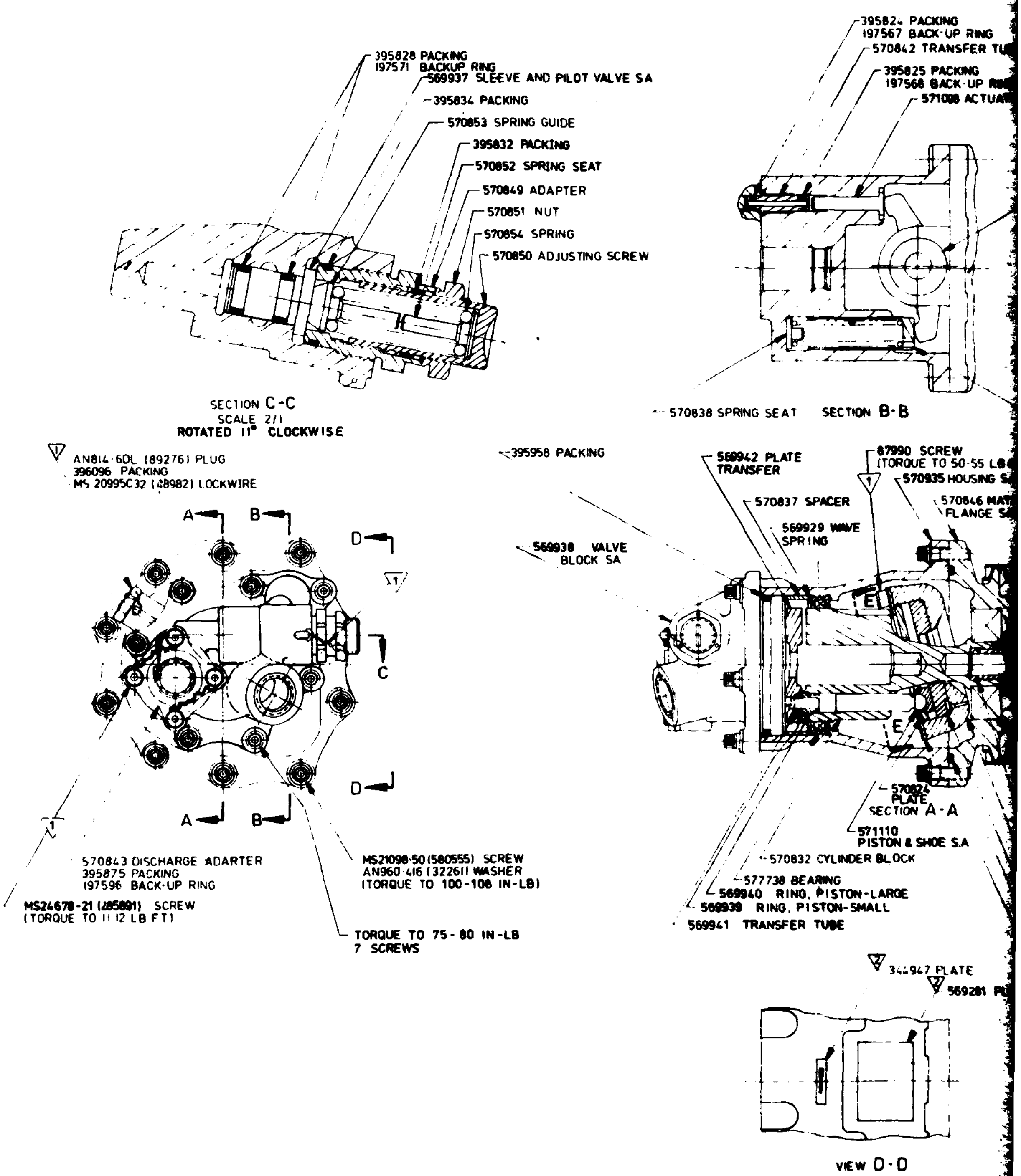
L	CODE IDENT NO. 89372	8696-580001
SCALE		SHEET 2 OF 2



2 ADHESIVE BOND PER VS1-3-4-14.

1 LOCKWIRE PER MS33540.

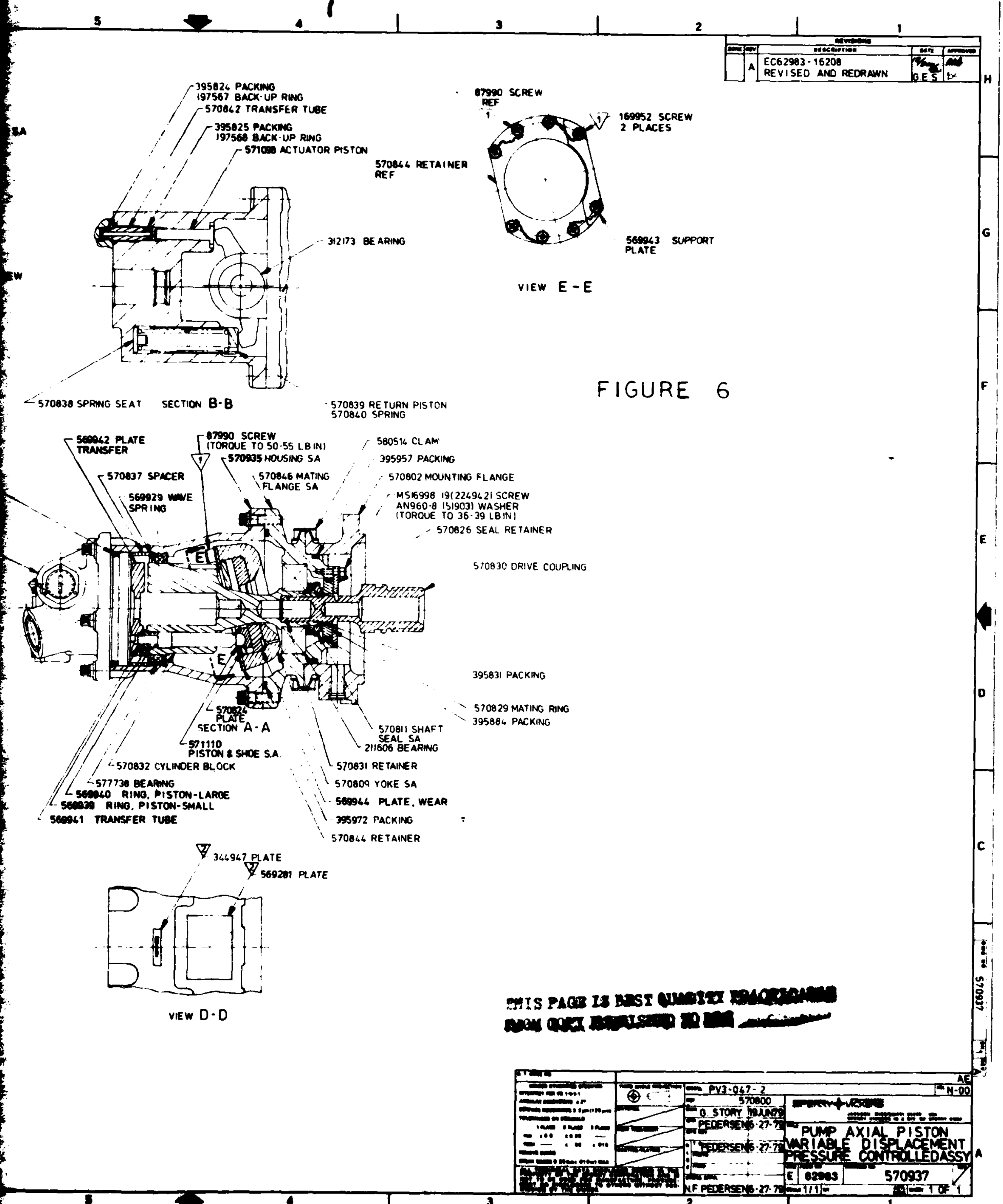
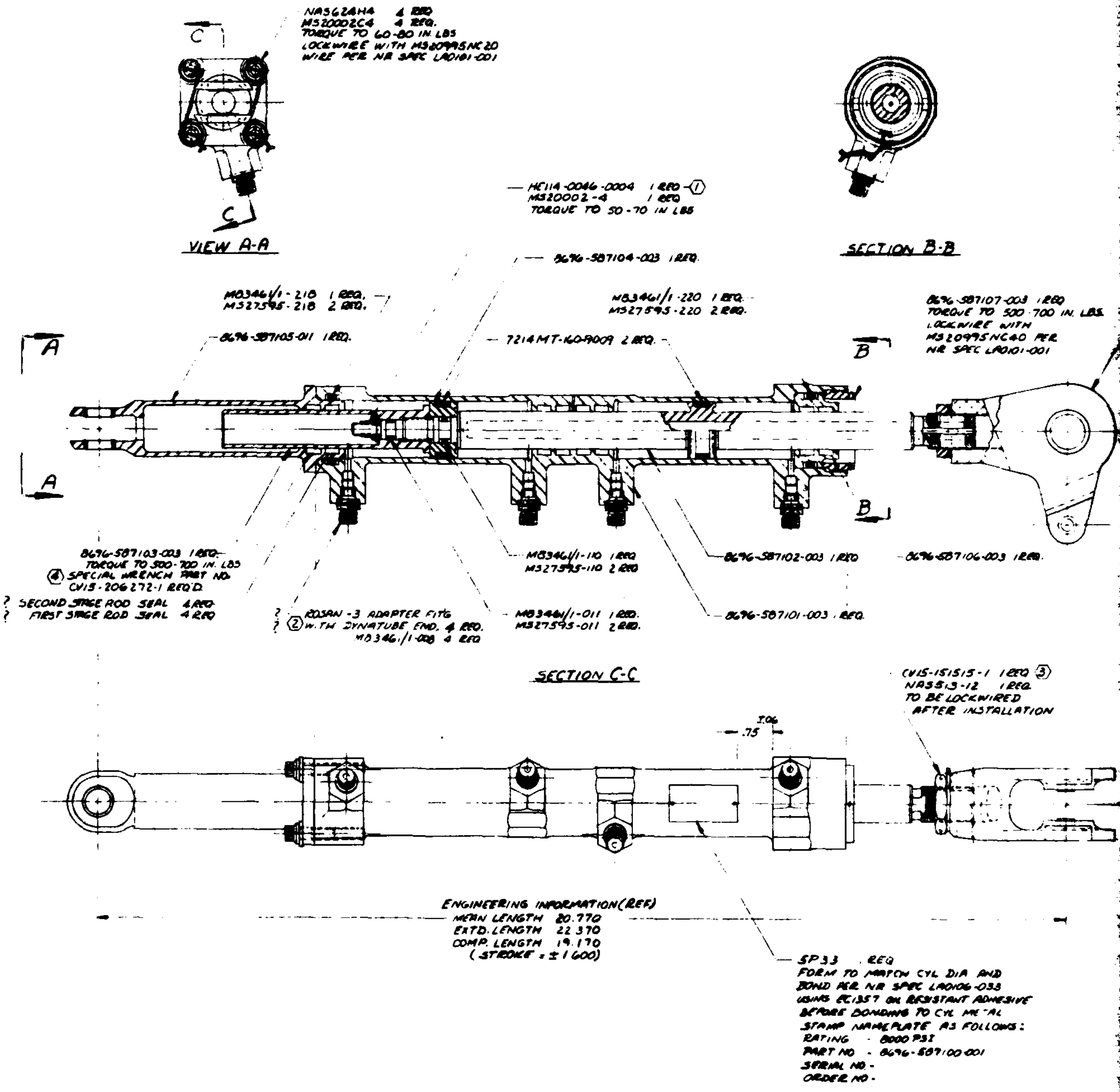

REVISIONS
A EC62983-16208 REVISED AND REDRAWN G.E.S
395824 PACKING
197567 BACK-UP RING
570842 TRANSFER TUBE
395825 PACKING
197568 BACK-UP RING
571098 ACTUATOR PISTON
570844 RETAINER REF
312173 BEARING
570838 SPRING SEAT
SECTION B-B
570839 RETURN PISTON
570840 SPRING
87990 SCREW REF
169952 SCREW 2 PLACES
569943 SUPPORT PLATE
VIEW E-E
569942 PLATE TRANSFER
87990 SCREW (TORQUE TO 50-55 LB IN)
570935 HOUSING SA
580514 CLAMP
395957 PACKING
570837 SPACER
570846 MATING FLANGE SA
570802 MOUNTING FLANGE
569929 WAVE SPRING
MS16998 19(224942) SCREW
AN960-8 (51903) WASHER
(TORQUE TO 36-39 LB IN)
570826 SEAL RETAINER
570830 DRIVE COUPLING
395831 PACKING
570829 MATING RING
395884 PACKING
570824 PLATE
SECTION A-A
570811 SHAFT SEAL SA
211606 BEARING
571110 PISTON & SHOE S.A.
570832 CYLINDER BLOCK
570831 RETAINER
577738 BEARING
570809 YOKE SA
569940 RING, PISTON-LARGE
569944 PLATE, WEAR
569939 RING, PISTON-SMALL
395972 PACKING
569941 TRANSFER TUBE
570844 RETAINER
344947 PLATE
569281 PLATE
VIEW D-D
PV3-047-2
570800
G. STORY 19JUN79
PEDERSEN 6-27-79
PEDERSEN 6-27-79
N.F. PEDERSEN 6-27-79
SPERRY VICKERS
PUMP AXIAL PISTON VARIABLE DISPLACEMENT PRESSURE CONTROLLED ASSY
E 62983 570937
1/1 SHEET 1 OF 1
N-00

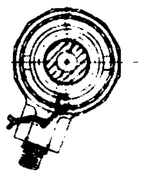
FIGURE 6



7. ASSEMBLE AND TEST PER NR SPEC HYS-2
6. RATED PRESSURE 8000 PSI
④⑤ 5. TO BE OBTAINED FROM:
VOUGHT CORPORATION, DALLAS, TEXAS 75222
② 4. INSTALL PER NR SPEC LA0102-014.
3. IDENTIFY PER NR SPEC LA0104-003.
① 2. VENDOR ITEM - SEE SPEC CONTROL DRAWING.
1. INSTALL THREADED FASTENERS PER NR SPEC LA0101-001.
NOTES: UNLESS OTHERWISE NOTED

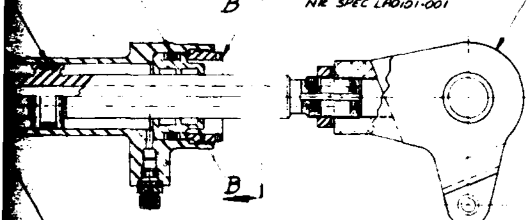
8-1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
		1 MAY BE REWORKED 2 CANNOT BE REWORKED 3 RECORD CHANGE 4 NOW SHOP PRACTICE 5 PARTS MADE OK		



SECTION B-B

FIGURE 7



...880 1 REQ.
...220 2 REQ.

8696-587107-003 1 REQ
TORQUE TO 500-700 IN. LBS.
LOCKWIRE WITH
MS20995NC40 PER
NR SPEC LA0101-001

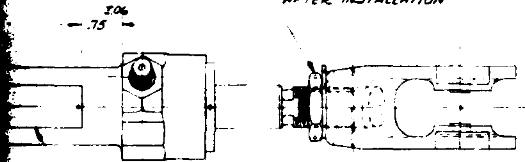
(3) CV15-151567-1 1 REQ.

8696-587102-003 1 REQ

8696-587106-003 1 REQ.

8696-587101-003 1 REQ.

CV15-151515-1 1 REQ. (3)
NAS513-12 1 REQ
TO BE LOCKWIRED
AFTER INSTALLATION



SP33 1 REQ
FORM TO MATCH CYL DIA AND
BOND PER NR SPEC LA0106-033
USING EC1357 OIL RESISTANT ADHESIVE
BEFORE BONDING TO CYL METAL
STAMP NAMEPLATE AS FOLLOWS:
RATING - 8000 PSI
PART NO - 8696-587100-001
SERIAL NO -
ORDER NO -

	ITEM OR FIND NO	QUANTITY REQUIRED -001	CODE IDENT	PART OR IDENTIFYING NUMBER	NOMENCLATURE	MATERIAL
(4)	037	1	80378	CV15-206272-1	SPECIAL TORQUE WRENCH	
	036	1		SP33	NAMEPLATE	
	035					
	034					
	033	4		?	ROD SEAL	
	032	4		?	ROD SEAL	
	031					
(2)	030	4		MB3461/1-008	PACKING	
(2)	029	4		? -3	ROSAN FTG.	
	028					
	027	2		7214MT-160-9009	G-T SEAL	
	026					
	025	2		MS27595-220	RETAINER	
	024	2		MS27595-210	RETAINER	
	023	2		MS27595-110	RETAINER	
	022	2		MS27595-011	RETAINER	
	021					
	020	1		MB3461/1-220	PACKING	
	019	1		MB3461/1-210	PACKING	
	018	1		MB3461/1-110	PACKING	
	017	1		MB3461/1-011	PACKING	
	016					
	015	4		MS20002C4	WASHER	
	014	1		MS20002-4	WASHER	
	013	4		NAS624H4	BOLT	
	012	1		NAS513-12	WASHER	
(1)	011	1		ME114-0046-0004	NUT	
(3)	010	1	80378	CV15-151567-1	ROD END	
(3)	009	1	80378	CV15-151515-1	NUT	
	008	1		8696-587107-003	NUT	
	007	1		8696-587106-003	RETAINER	
	006	1		8696-587105-011	CAP	
	005	1		8696-587104-003	PISTON	
	004	1		8696-587103-003	EXTENSION	
	003	1		8696-587102-003	PISTON ROD	
	002	1		8696-587101-003	CYLINDER	
	001			8696-587100	ACTUATOR ASSY	

PARTS LIST

-001	1		
ITEM	QTY	NEXT ASSY	USED ON
REQD PER END ITEM		APPLICATION	EFFECTIVITY

HEAT TREAT
FINISH

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES MFG TOLERANCES ON UNDIMENSIONED .XX (DECIMALS) ± .03 .XXX (DECIMALS) ± .010 ANGLES ± 30'
DO NOT SCALE PRINT

CONTR NO
DWN BY MATCHETT 2-4-79
CHK BY L. SHAFFER 4-20-79
APVD

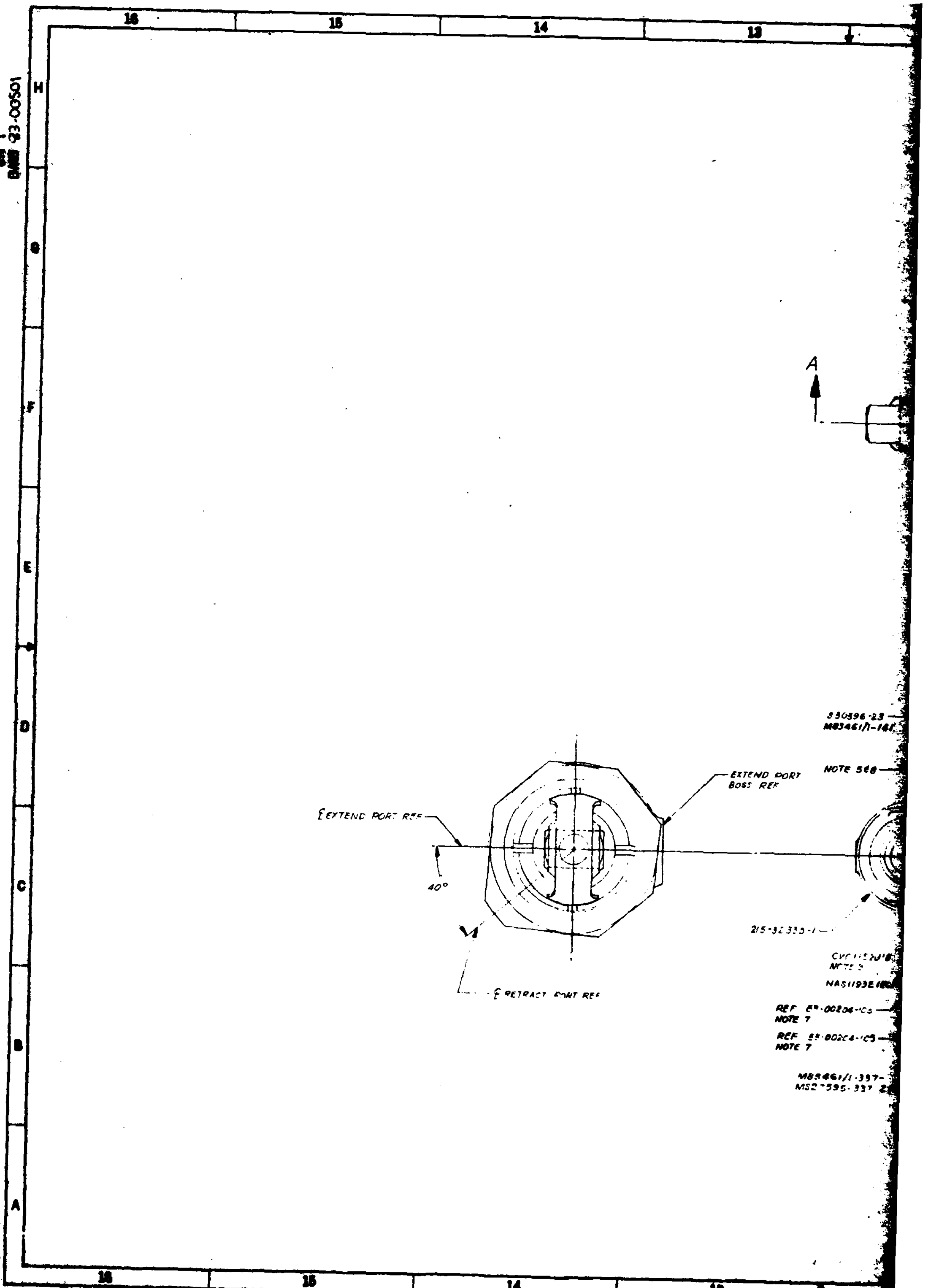
Rockwell International Corporation
Columbus Aircraft Division

ACTUATOR ASSEMBLY - RUDDER
LIGHTWEIGHT HYDRAULIC SYSTEM

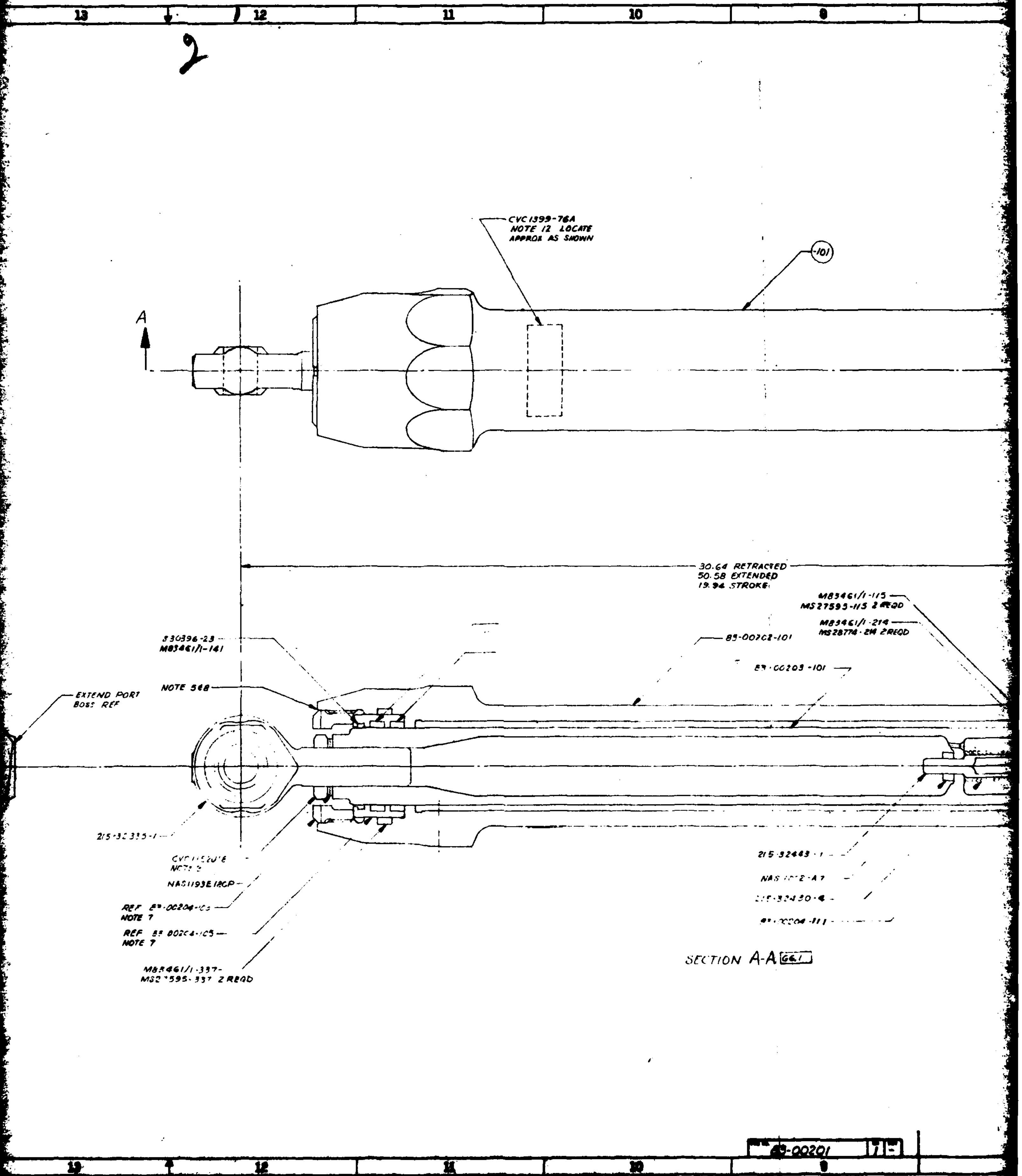
SIZE E | CODE IDENT NO 89372 | 8696-587100

8696-587100

NHC HYS-2
MS 75222
DRAWING.
NR SPEC LA0101-001.



16
15
14
13
H
G
F
E
D
C
B
A
EXTEND PORT REF
EXTEND PORT BOSS REF
40°
RETRACT PORT REF
NOTE 5&8
NOTE 7
NOTE 7



13
12
11
10
9
CVC 1399-76A
NOTE 12 LOCATE
APPROX AS SHOWN
-101
A
30.64 RETRACTED
50.58 EXTENDED
19.94 STROKE
M83461/1-115
MS27595-115 2 REQD
M83461/1-214
MS28774-214 2 REQD
M83461/1-141
83-00203-101
NOTE 5&8
EXTEND PORT
BOSS REF
215-32443-1
REF
NOTE 7
REF
NOTE 7
SECTION A-A
83-00201

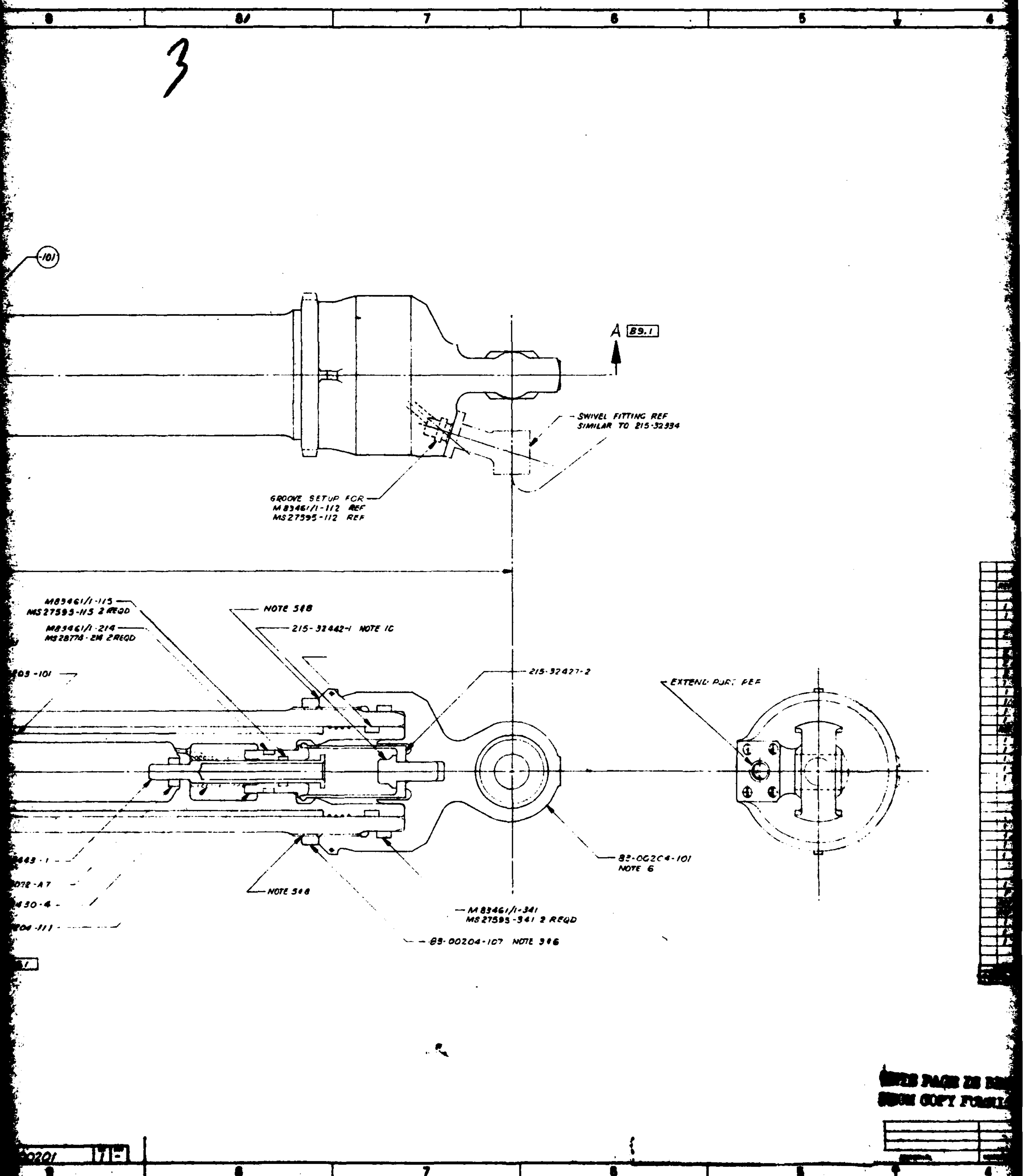


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FIGURE 8

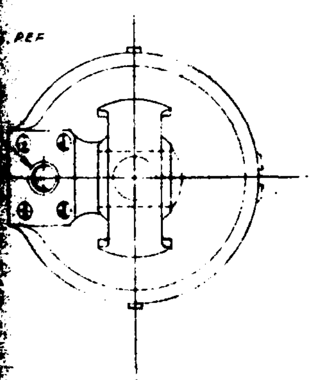
NOTES

1. THIS UNIT TO OPERATE WITH HYDRAULIC FLUID IN ACCORDANCE WITH SPEC MIL-H-5606 OR MIL-H-83282
2. OPERATING PRESSURE 8000 PSI (NOM)
3. LOCKWIRE PER SPEC CVA 13-480
4. ASSEMBLE ACTUATOR IN ACCORDANCE WITH SPEC CVA 12-170
5. FILLET SEAL PER CVA 177(2)
6. TORQUE 83-00204-107 NUT TO 300 ± 25 FT LBS WITH NO LOAD ON ACTUATOR. ASSURE PROPER PORT ALIGNMENT AFTER TORQUING. CAP MAY BE BACKED OFF UP TO 359° FROM BOTTOMED POSITION TO ACHIEVE PORT ALIGNMENT. ALIGN PORTS AS SHOWN ON DRAWING.
7. INSTALL SEALS IN RETAINER AND HOUSING AND INSTALL RETAINER IN HOUSING SO THAT ALIGNMENT MARKS LINE UP. INSTALL 83-00204-103 RING AND TORQUE TO 600 ± 100 IN LB
8. SEAL NOTED AREA USING EC 1126 MINNESOTA MINING AND MFG CO., LOS ANGELES, CALIF. CODE IDENT 04633
9. ACCEPTANCE TEST ASSY PER SPEC
10. TORQUE TO 800 TO 1000 IN LB.
11. AREAS AND VOLUMES:

FUNCTION	EFFECTIVE AREA	REQD OPER VOLUME
EXTEND	$5.38\ IN^2$	$107.34\ IN^3$
RETRACT	$1.414\ IN^2$	$28.20\ IN^3$

12. BOND NAMEPLATE TO ACTUATOR PER SPEC CVA 6-177(7)
13. GENERAL PROTECTIVE SPEC CVA 208-9-220. FOR DEFINITION OF PROTECTIVE FINISH CODE NUMBERS AND APPLICABLE GOV SPECS, SEE CVA 78-21. SEE SPEC 208-13-36 FOR APPROVED MATERIAL SUBSTITUTIONS. SEE SPEC 208-13-157 FOR AUTHORIZED STD PARTS SUBSTITUTION.

REF



REF			INSERT		
1		NAS1193E18CP	LOCKING DEVICE		.024
1		NAS1072A7	NUT		.013
2		MS28774-214	BACKUP RING		.0018
2		MS27595-341	BACKUP RING		.0129
2		MS27595-337	BACKUP RING		.0110
2		MS27595-115	BACKUP RING		.0009
1		M83461/1-341	PACKING		.028
1		M83461/1-337	PACKING		.024
1		M83461/1-214	PACKING		.0038
1		M83461/1-[illegible]	PACKING		.0044
1		M83461/1-[illegible]	PACKING		.0016
REF		M83461/1-[illegible]	PACKING		
1		CVC1399-76A	NAMEPLATE	12	.002
1		CVC1152J18	NUT, JAM		.141
1	D7.1		SEAL, PISTON		
1	D11.1		SEAL, ROD		
1	D12.1	830[illegible]-29	EXCLUDER		
1	C9.1	215-32449-1	LOCK PI[illegible]		.23
1	B9.1	215-32430-4	SPRING		.10
1	D6.1	215-32427-2	FINGER LOCK		.37
1	D8.1	215-32442-1	BOLT		.13
1	C13.1	215-32335-1	ROD END ASSY		2.45
1	B9.1	83-00204-111	PISTON		.35
1	B7.1	83-00204-107	NUT, LOCK	6	.11
REF	B12.1	83-00204-105	RETAINER, SEAL	7	
REF	B12.1	83-00204-103	RING LOCK	7	
1	C6.1	83-00204-101	END CAP ASSY		9.75
1	D9.1	83-00203-101	PISTON & ROD		14.16
1	D9.1	83-00202-101	HOUSING ASSY		15.27
	C9.1	-101	ACTUATOR ASSY	4.9	43.29

RELEASE AUTHORITY

SHEET

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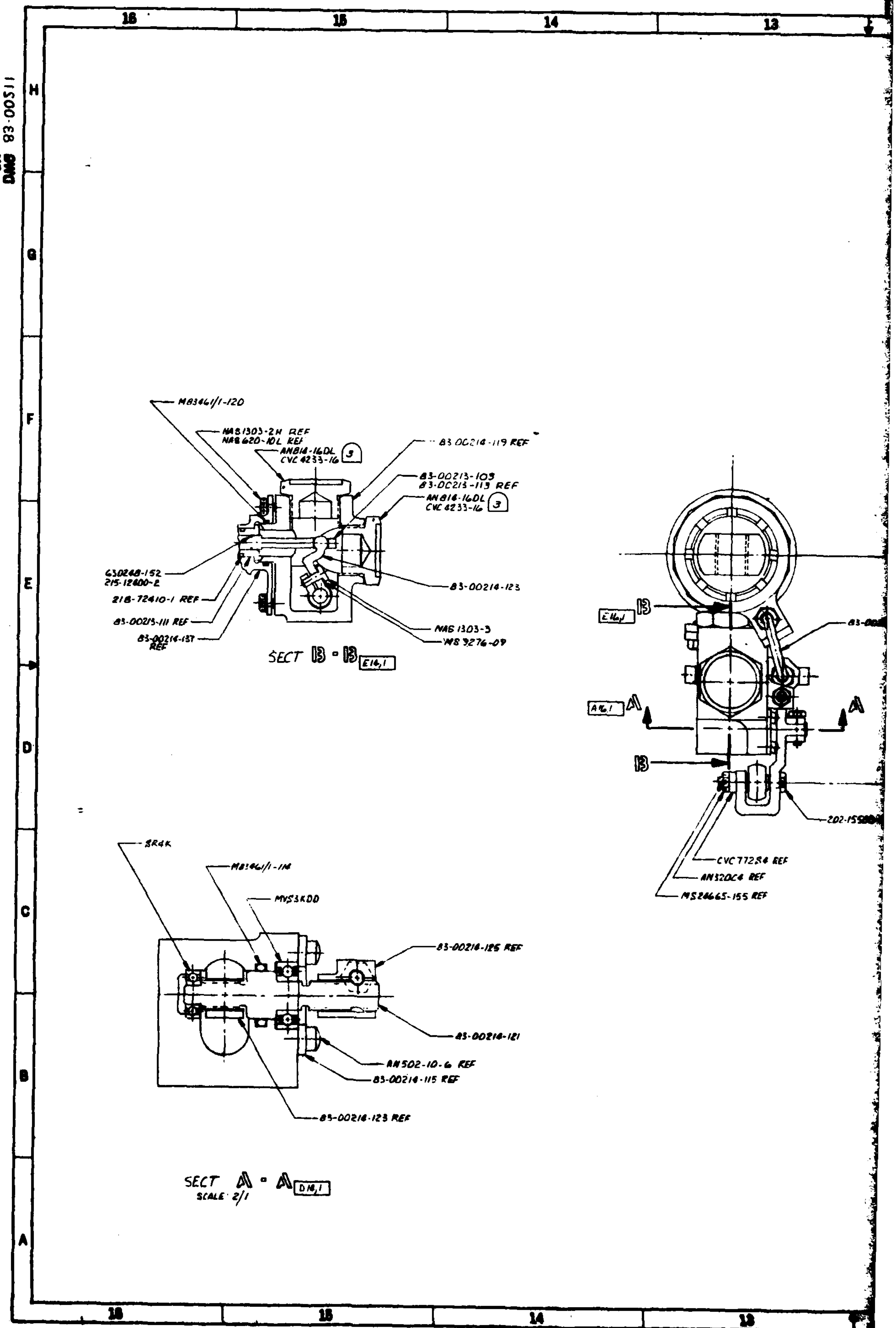
ACTUATOR ASSY-SPEED BRAKE LT NT HYD SYSTEM

83-00201

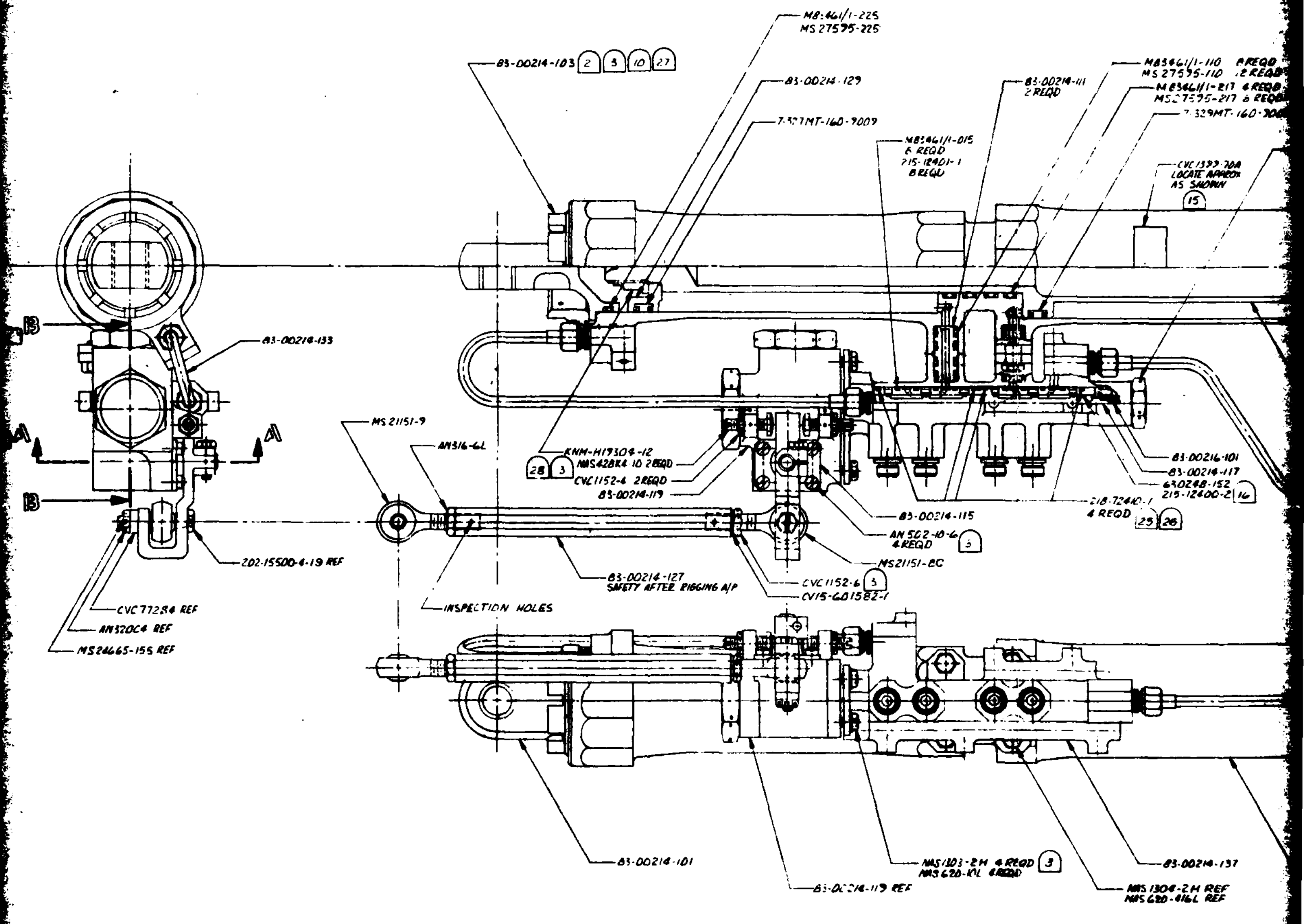
MATERIAL SPECIFICATION | PROTECTIVE FINISH

DWG 83-00511
SH 1



13 12 11 10 9

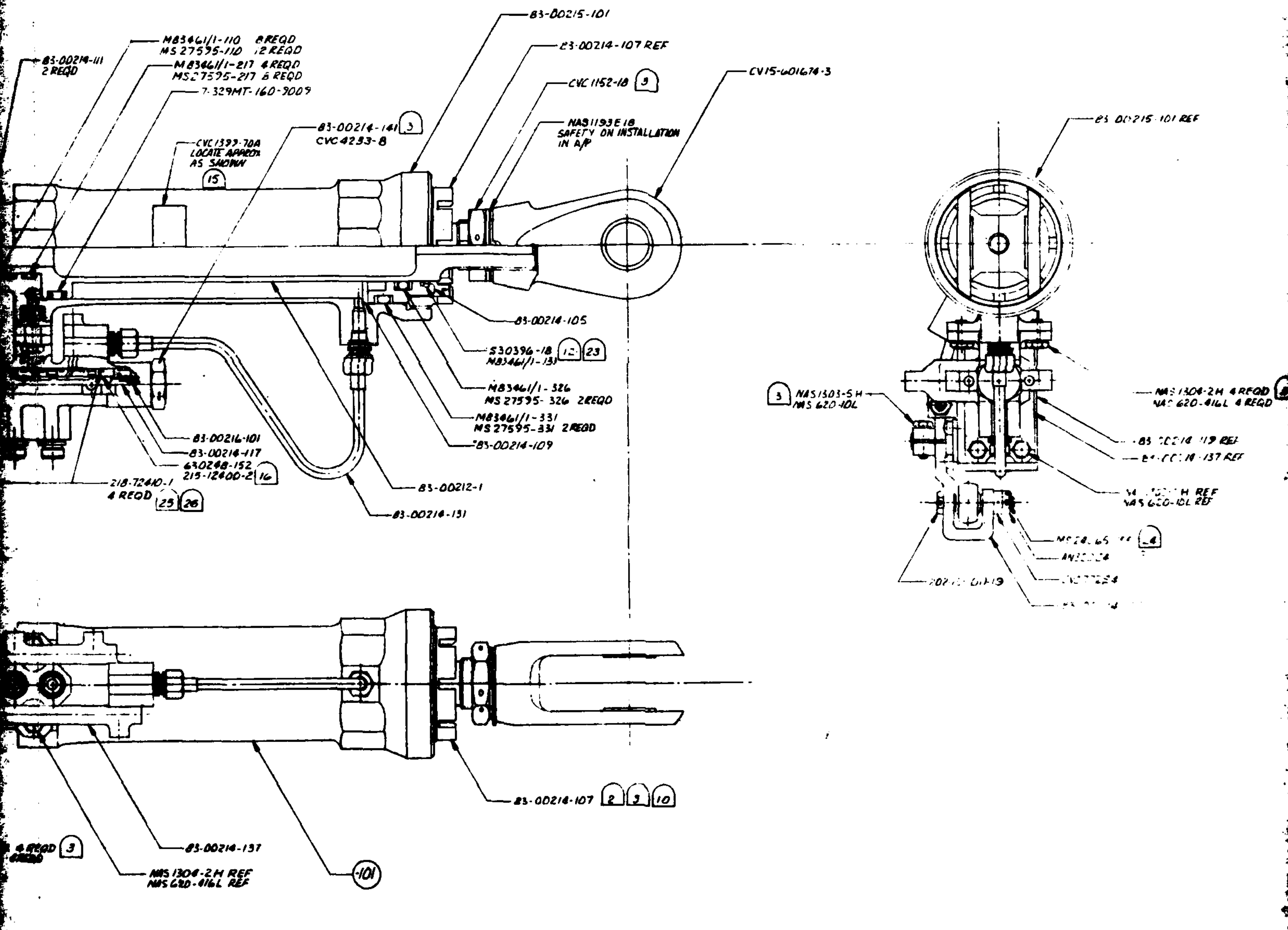
2



83-00211 7 -

13 12 11 10 9

3



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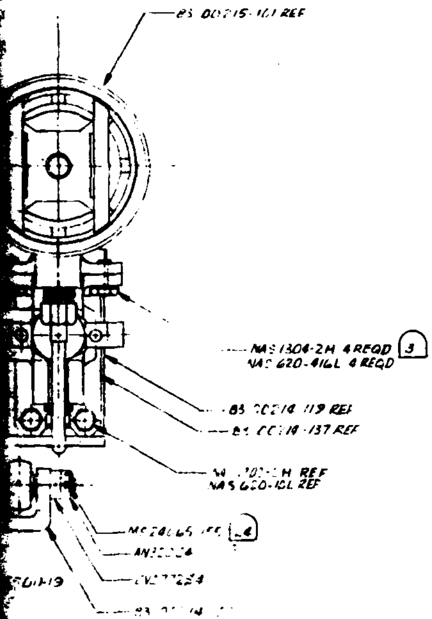
83-00211 7

4

RELEASE AUTHORITY ER 10411-7

FIGURE 9



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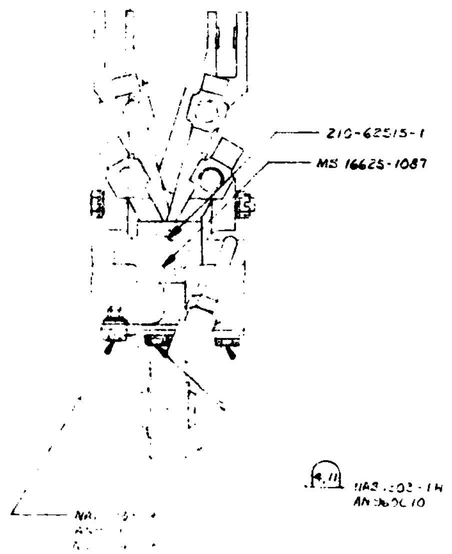
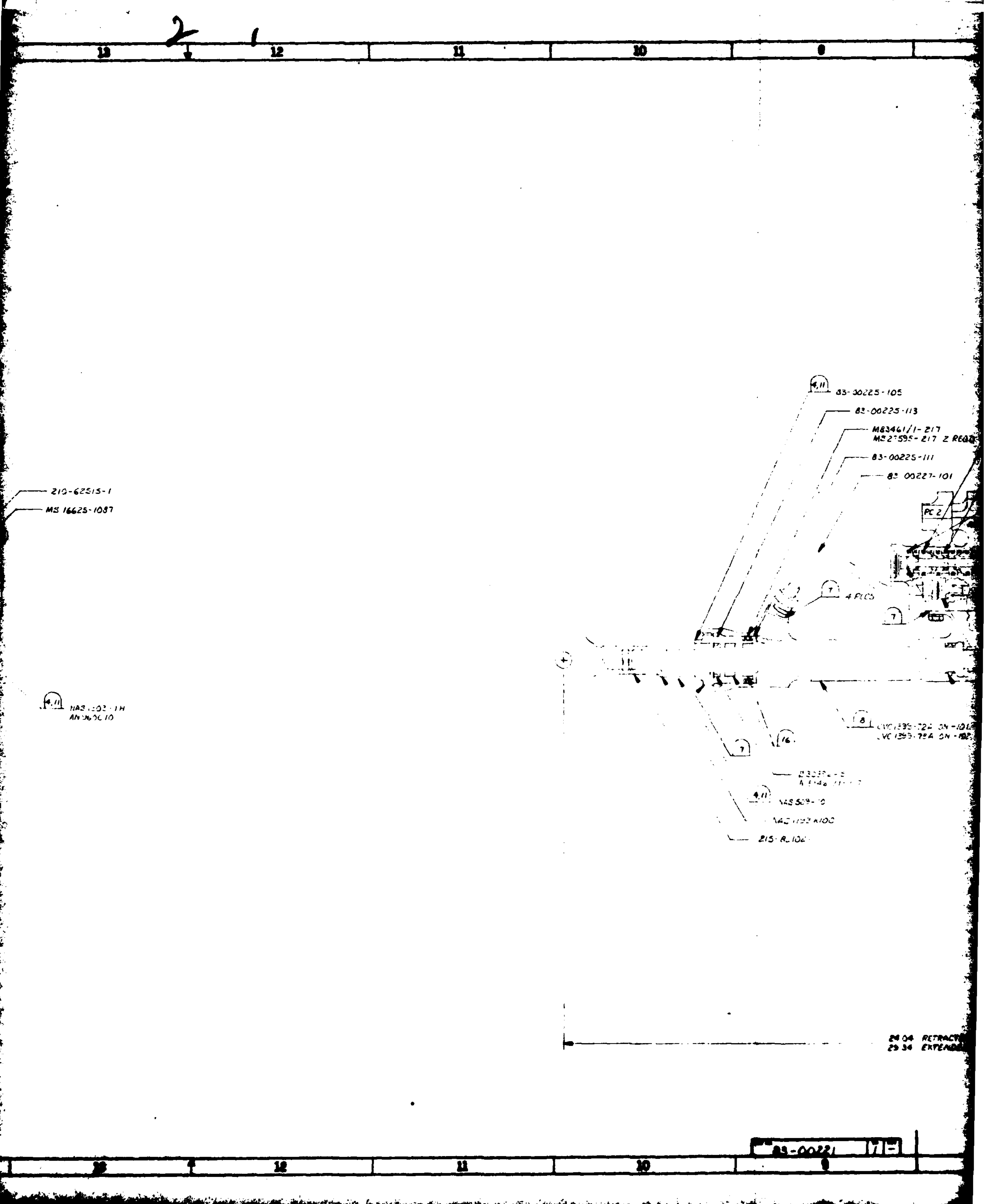
VOUGHT CORPORATION

ACTUATOR ASSY, UHT PC SERVO-
LT WT HYD SYSTEM

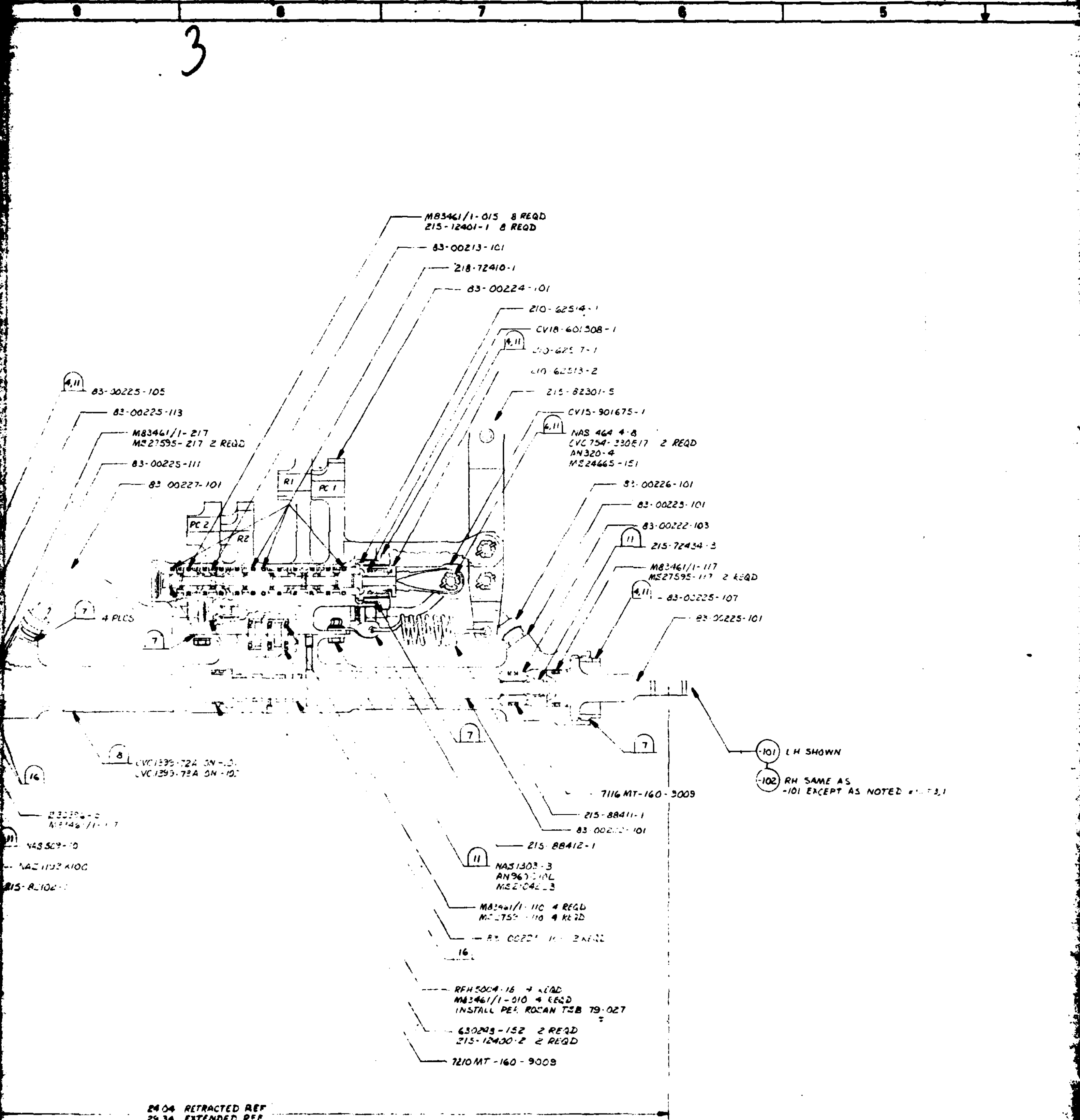
83-00211


210-62515-1
MS 16625-1087
4.11
NAS 1303-1H
AN960C10



13
12
11
10
9
83-00225-105
83-00225-113
M83461/1-217
MS27595-217 2 REQD
83-00225-111
83 00227-101
PC 2
4 PLCS
210-62515-1
MS 16625-1087
NAS 509-10
215-RJ102
24.04 RETRACTED
25.34 EXTENDED
83-00221

3



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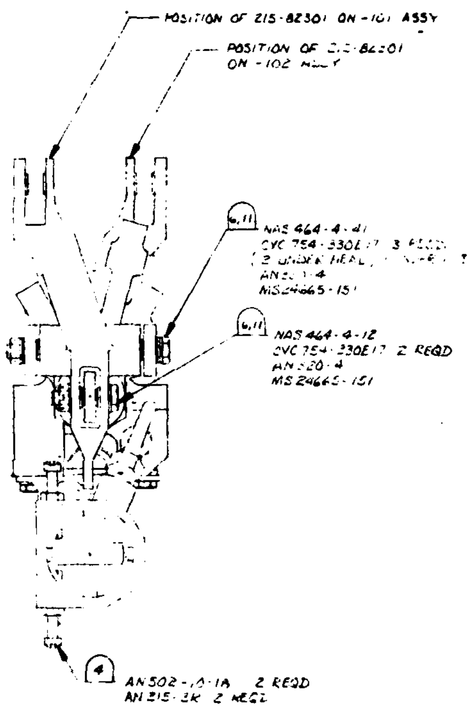
83-00221

FIGURE 10



(101) LH SHOWN

(102) RH SAME AS -101 EXCEPT AS NOTED

ACTUATOR ASSY, AILERON PC SERVO - LT WEIGHT HYD SYSTEM

83-00221

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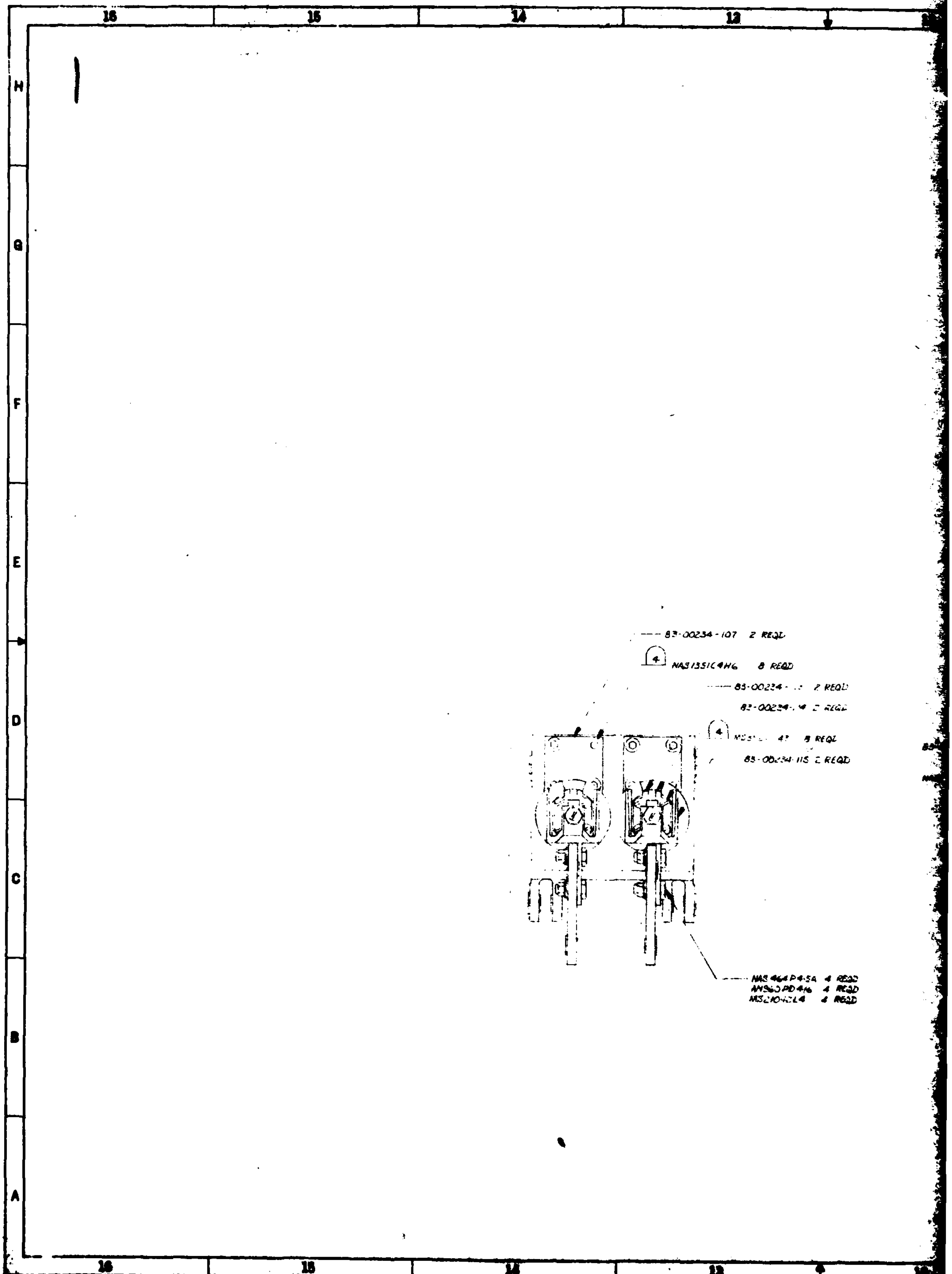
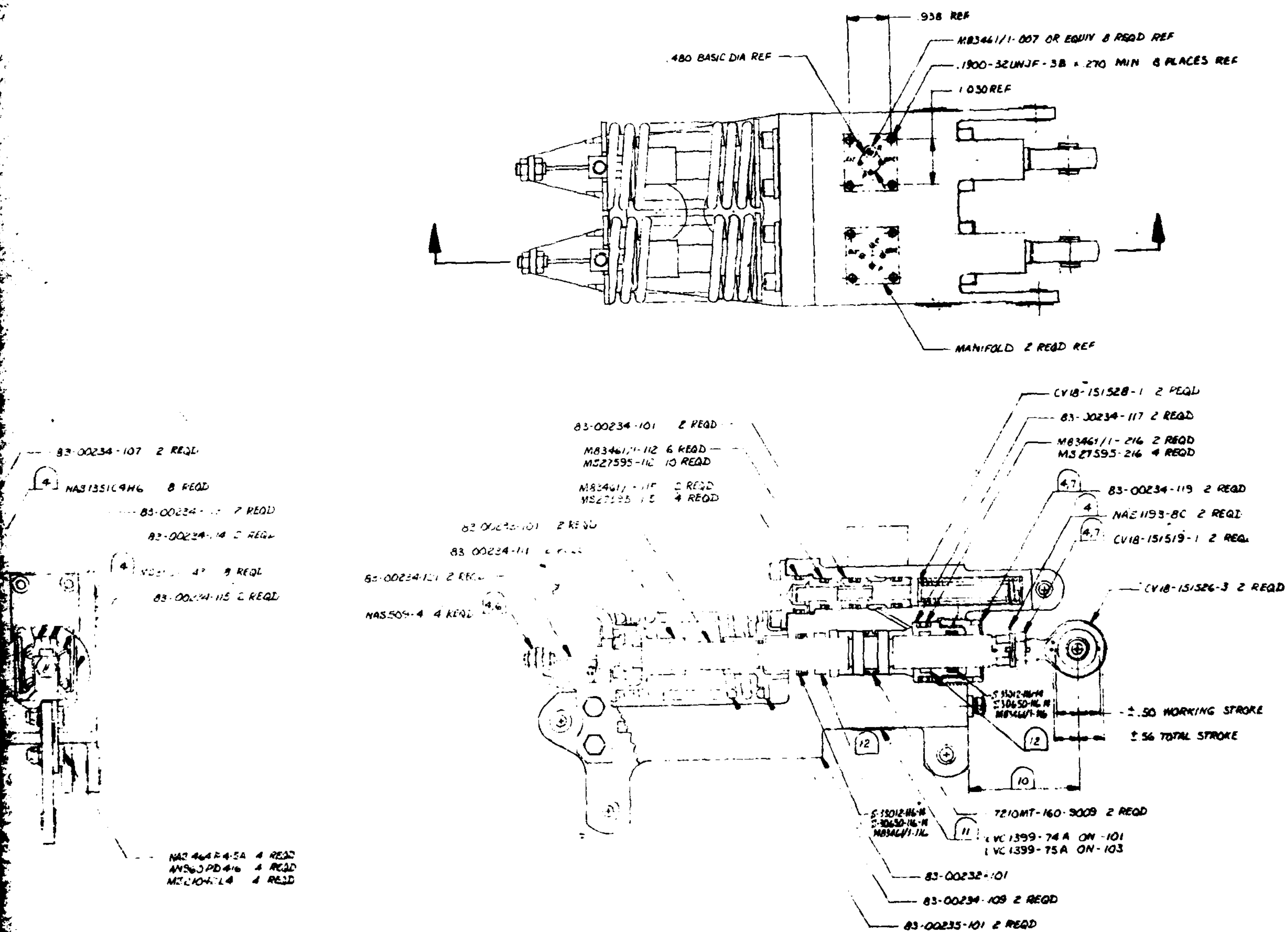


83-00234-107 2 REQD
4
NAS1351C4H6 8 REQD
2 REQD
4
8 REQD
83-00234-115 2 REQD
NAS464P4-5A 4 REQD
AN960PD416 4 REQD
4 REQD

13 12 11 10 9

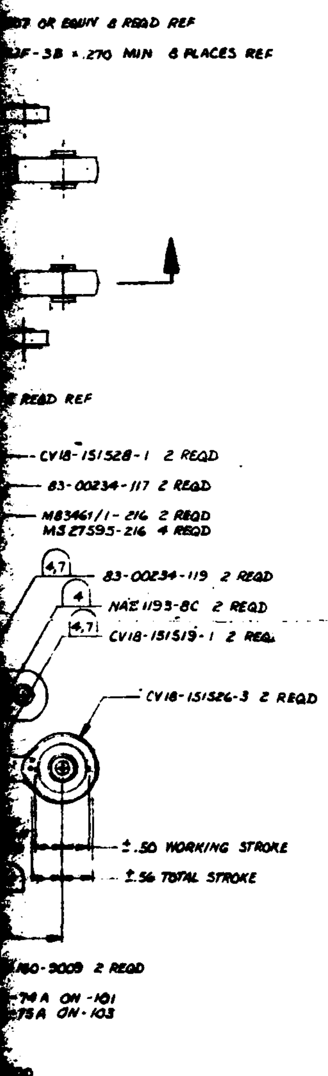
2 1

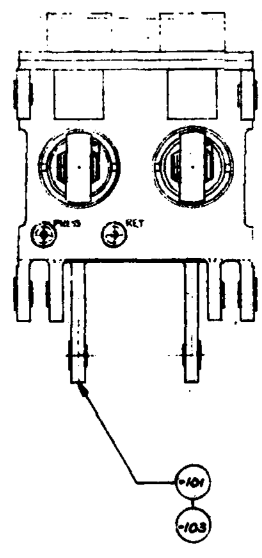


83-00231

13 12 11 10 9

3





-00231

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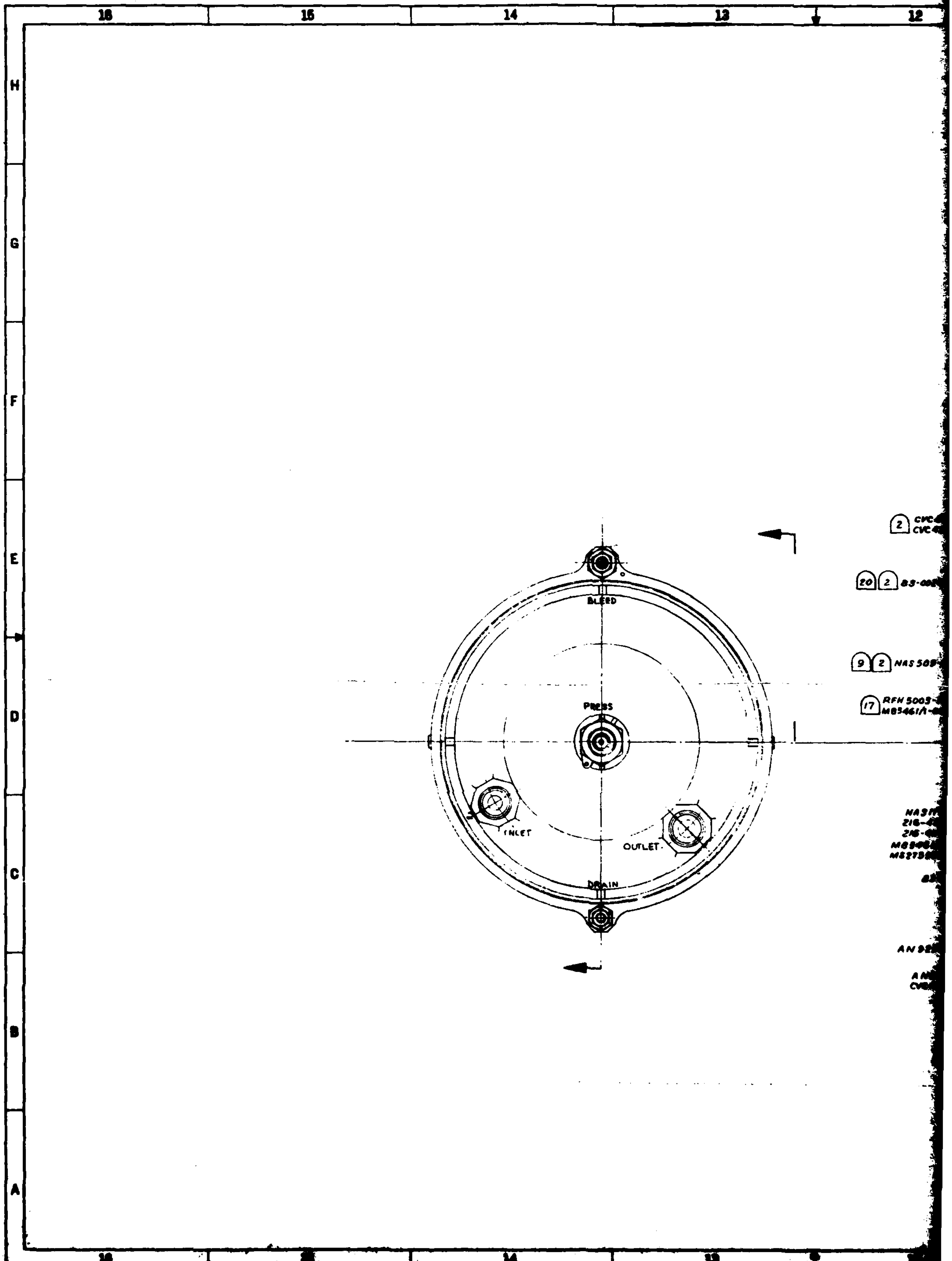
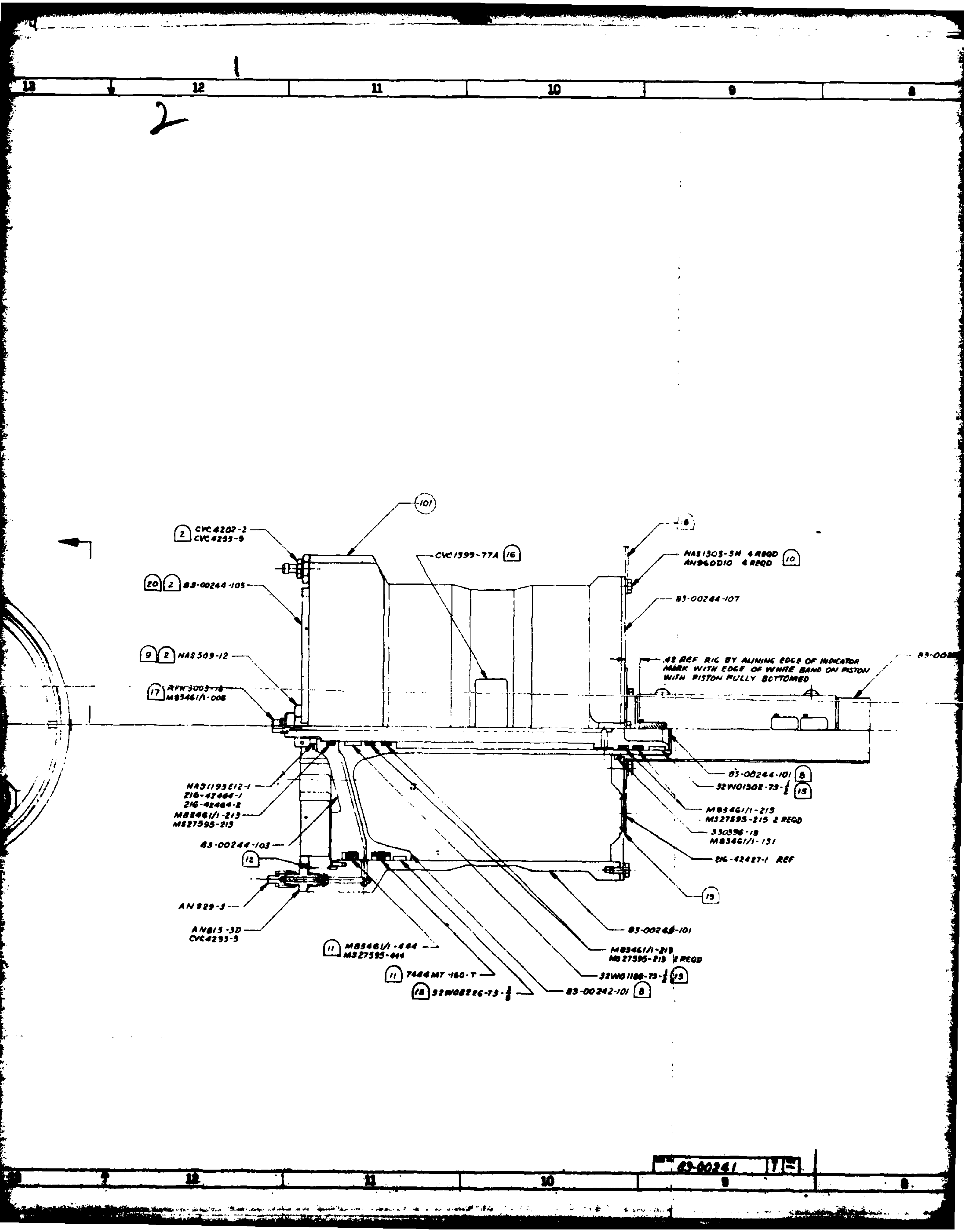
FIGURE 11

ACTUATOR, STABILIZATION
LIGHTWEIGHT HYD SYSTEM

83-00231


BLEED
PRESS
INLET
OUTLET
DRAIN



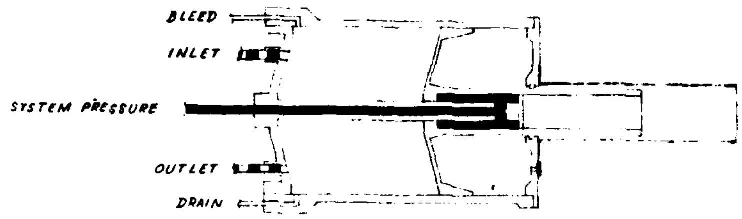
1
2
13
12
11
10
9
8
-101
2 CVC4202-2
CVC4255-5
CVC1399-77A 16
8
NAS1303-3H 4 REQD
AN960D10 4 REQD 10
20 2 83-00244-105
83-00244-107
9 2 NAS509-12
.42 REF RIG BY ALINING EDGE OF INDICATOR MARK WITH EDGE OF WHITE BAND ON PISTON WITH PISTON FULLY BOTTOMED
17 RFN3003-18
M83461/1-008
NAS1193E12-1
216-42464-1
216-42464-2
M83461/1-213
MS27595-213
83-00244-103
12
AN929-3
AN815-3D
CVC4233-3
83-00244-101 8
32W01302-73-1/2 15
M83461/1-215
MS27595-215 2 REQD
330396-18
M83461/1-131
216-42427-1 REF
19
83-00244-101
M83461/1-213
MS27595-213 2 REQD
11 M83461/1-444
MS27595-444
11 7444MT-160-T
18 32W08226-73-1/8
32W01100-73-1/2 15
83-00242-101 8
83-00241

3

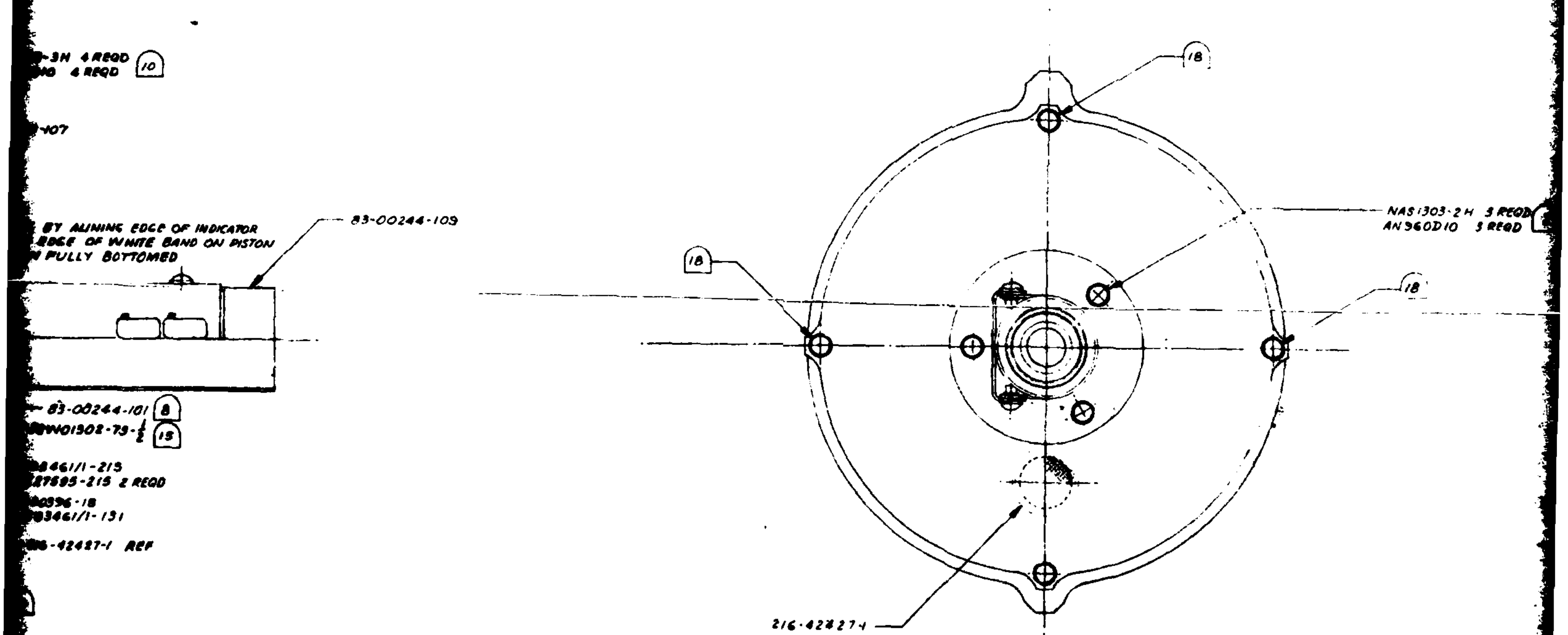
ENGINEERING REFERENCE INFORMATION

SCHEMATIC - HYDRAULIC

SCALE NONE



RESERVOIR PISTON NET AREA 52.46 IN²
PRESSURIZATION PISTON NET AREA .647 IN²
RATIO: $\frac{52.46\,IN^2}{.647\,IN^2} = \frac{81.08}{1} = \frac{8000\,PSI}{98.67\,PSI}$



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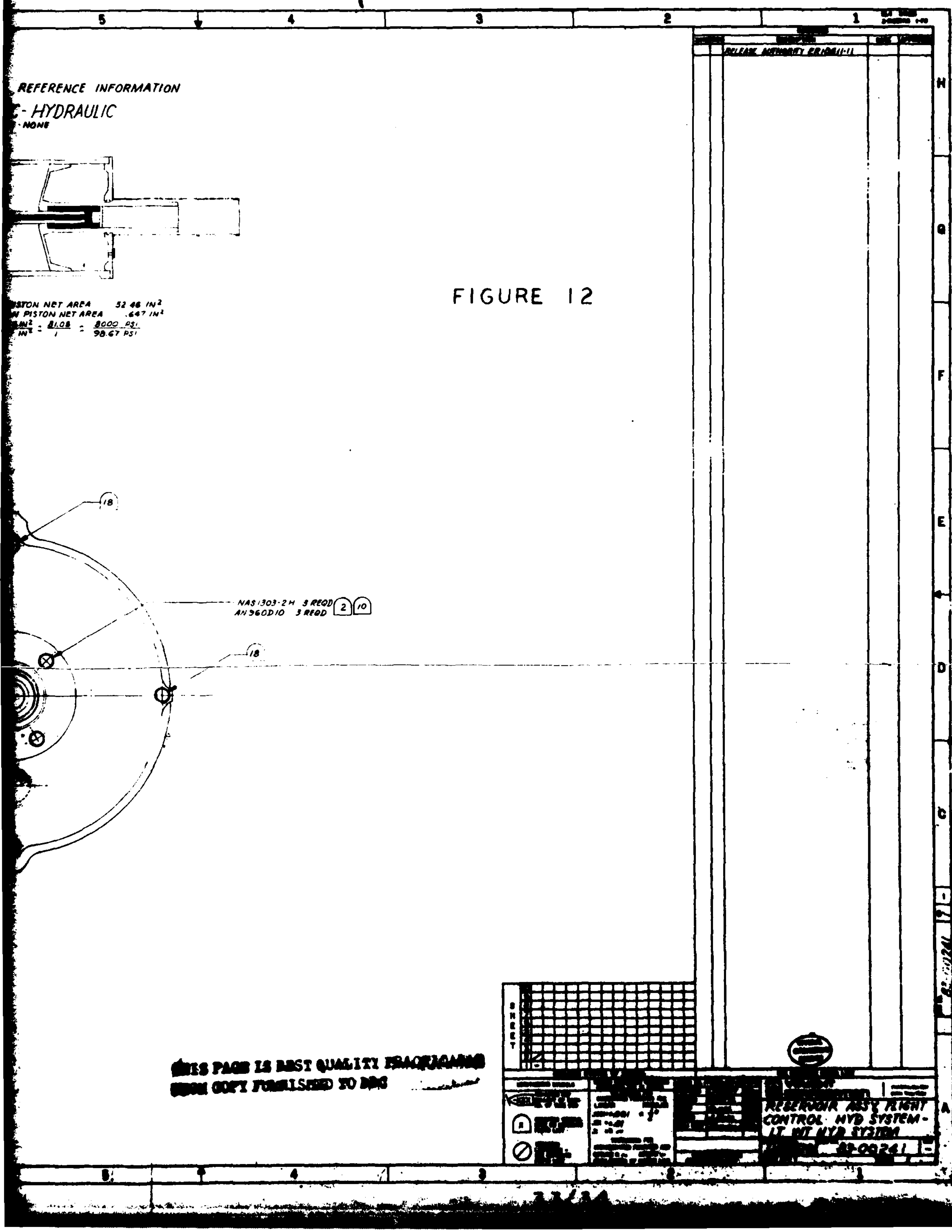


REFERENCE INFORMATION
- HYDRAULIC
NONE
PISTON NET AREA 52.46 IN²
PISTON NET AREA .647 IN²
81.08
8000 PSI
98.67 PSI
NAS1303-2H 3 REQD
AN960D10 3 REQD
2
10
18
18
RELEASE AUTHORITY
RESERVOIR ASSY FLIGHT CONTROL HYD SYSTEM - LT WT HYD SYSTEM
SHEET
5
4
3
2
1
H
G
F
E
D
C
B
A

FIGURE 12

The 8000 psi actuators were designed for the same end attach points, kinematics, load, stroke, and rate requirements as the equivalent 3000 psi actuators. Conventional design techniques and fabrication procedures were employed for all the test units. Design proof and burst pressures were 12,000 and 16,000 psi, respectively. The rudder, UHT, and aileron actuator bodies are steel; the AFCS and speed brake actuator bodies are aluminum. Control valve orifices were sized for the lower flow rates which occur at 8000 psi, and were overlapped to minimize internal leakage. Pertinent information covering each actuator fabricated is summarized below:

Actuator	Working Stroke, in.	Max. Output Force, lb. (2 sys.)	No-Load Stroke Time, sec.	Max. Flow, gpm (1 sys.)
Rudder	2.9	11,104	0.6	1.04
Speed Brake	19.9	43,064	7.0	*4.0
UHT	5.7	54,400	1.3	**3.9
Aileron	5.0	9,568	0.5	1.6
AFCS	1.0	2,656	0.32	0.86

*4 gpm restrictor limits rate in test system.
**3.9 gpm needed to meet surface velocity requirements; however, control valve designed to provide 6.0 gpm to meet time constant requirements.

The rod seal configurations were selected on the basis of evaluation tests discussed in section 5.1. The primary flight control actuators (rudder, UHT, and aileron) have a two stage unvented seal as shown on Figure 13. The speed brake actuator has a single stage seal with trapezoidal shaped cross-sections, Figure 14. The AFCS actuator has a single stage cap seal, Figure 15. This configuration was used instead of the trapezoidal seal because of the need for lower rod seal friction.

Rod seal gland dimensions were per MIL-G-5514 except 1) diametral clearance was 0.001 to 0.003 inch, and 2) groove depth tolerance was 0.001 inch. These limitations reduced the extrusion gap and minimized variations in packing squeeze due to tolerance buildups.

The piston seal configuration was selected on the basis of tests reported in Reference 10. The packing has a 'T' shaped cross-section and is supported by backup rings as shown on Figure 16.

Standard MS static seals were used for boss and diametral type applications in all LHS actuators. Standard MS seals were also employed in Rosan connector installations.

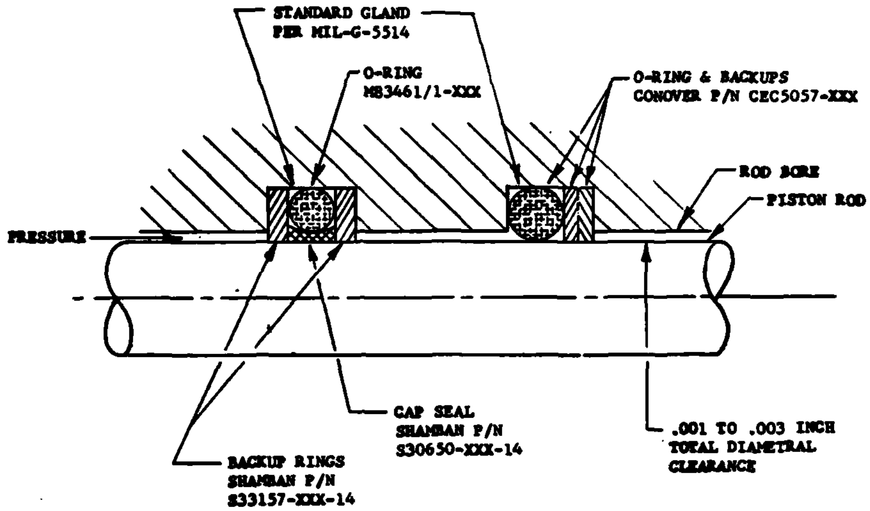


FIGURE 13. Rod seals in flight control actuators

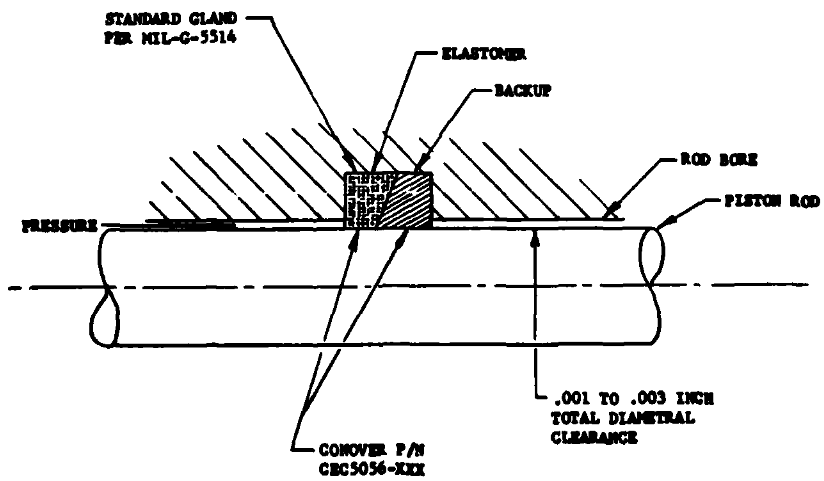


FIGURE 14. Rod seals in utility actuators

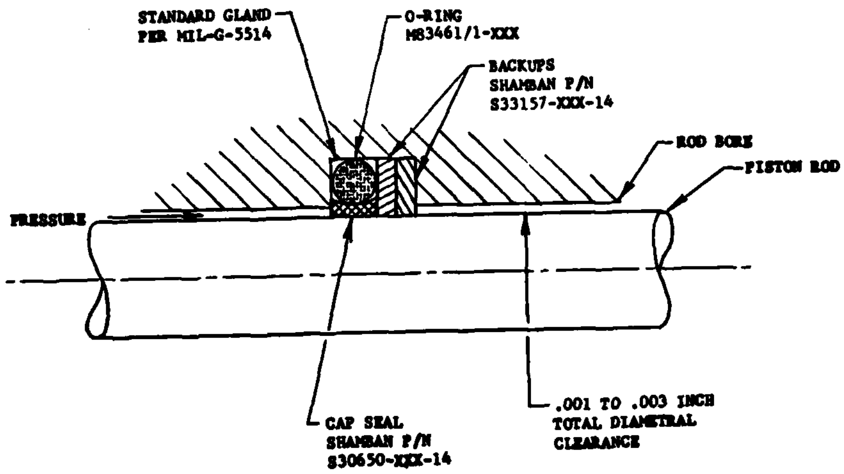


FIGURE 15. Rod seal in AFCS actuator

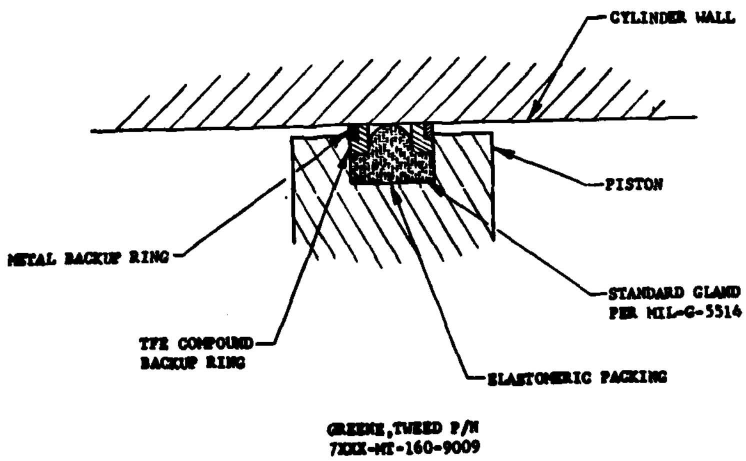


FIGURE 16. Piston seal

The AFCS actuator will have two single-stage, direct-drive electro-hydraulic control valves--one for each cylinder. Development of these valves is planned in Phase II of the LHS program. An interim direct-drive valve was used to operate the AFCS actuator in Phase I. Major components of the interim valve were:

Description	Remarks
Force Motor General Electric P/N 55-666102 (see Figure 36)	Developed during program reported in Reference 13
Valve Assembly NAAD-Columbus P/N S.O. 4248-41 (see Figure 36)	Designed and fabricated during program reported in Reference 13
Electronic Drive Unit NAAD-Columbus P/N 8696-546604 (see Figure 37)	Designed and fabricated during program reported in References 14 and 15

3.1.3 Reservoir

The LHS reservoir was designed and fabricated by Vought Corporation and is identified as P/N 83-00241. The FC-1 and FC-2 reservoirs are identical, and similar in concept to the existing PC-1 and PC-3 reservoirs except for porting and capacity, Figure 12. The LHS reservoirs have a port for system return; the A-7 reservoirs do not. The FC-1 and FC-2 reservoirs each have a design capacity of 320 in^3; an equivalent design reservoir for a 3000 psi system would have a capacity of 500 in^3. Application of 8000 psi to the reservoir bootstrap port provides reservoir pressurization of 90 psig. The low pressure sections have design proof and burst pressures of 180 and 270 psi, respectively. The bootstrap section has proof and burst pressures of 12,000 and 16,000 psi, respectively.

3.2 MINOR COMPONENTS

Minor components procured for evaluation testing are listed in Table 1. Part number, manufacturer, and general design information are given for each component. Photographs of the components are presented on Figures 17 through 26. Design proof and burst pressures at +275°F were as follows:

Component	Proof Pressure	Burst Pressure
check valve filter pressure gage pressure snubber pressure transmitter quick disconnect relief valve restrictor solenoid valve	12,000 psi	16,000 psi
accumulator fittings hose tubing	16,000 psi	24,000 psi

3.3 SPECIFICATIONS

Under the data requirements of the contract between the Navy and Rockwell, a set of preliminary specifications were prepared and provided for use in defining system, general components, detail component, and process requirements for 8000 psi lightweight hydraulic systems. These documents were prepared and submitted to the Navy Project Office under separate cover, Reference 12. The basis under which these documents were prepared was to use the comparable 3000 psi Military Specifications, update those where required for 8000 psi, and restructure the specification formats to be consistent with MIL-STD-961, which was the specification preparation requirement of the contract.

A total of 34 specifications were written. The LHS documents with the subcontractor's specifications were used for procurement of test system components fabricated in Phase I. The LHS specifications are listed in Appendix A.

TABLE 1. Minor Components

DESCRIPTION	PART NO.	MANUFACTURER	FIGURE NUMBER	DESIGN INFORMATION
ACCUMULATOR	3321471	BENDIX ELECTRODYNAMICS NORTH HOLLYWOOD, CA	17	1. MIN. GAS VOL.: 2in^3 MAX.OIL VOL.: 9in^3 2. STEEL CONSTRUCTION 3. TWO-STAGE BACKUP RINGS ON PISTON 4. ONE DIAMETRAL STATIC SEAL
CHECK VALVE	95200	GAR-KENYON CONTROLS NEW HAVEN, CT	18	1. STANDARD DESIGN 2. STEEL CONSTRUCTION 3. ONE DIAMETRAL STATIC SEAL
FILTER	AD-A640-03Y1	AIRCRAFT POROUS MEDIA PINELLAS PARK, FL	19	1. RATED FLOW: 10 gpm 2. FILTRATION: 5μ abs 3. TITANIUM CONSTRUCTION 4. TWO DIAMETRAL STATIC SEALS
FITTINGS	SEE TABLE 2.	THE DEUTSCH COMPANY LOS ANGELES, CA	20	1. EXTERNALLY SWAGED FITTING 2. PERMANENT AND SEPARABLE CONNECTIONS 3. LIP SEAL TYPE SEPARABLE FITTINGS
		RAYCHEM CORPORATION MENLO PARK, CA	21	1. HEAT SHRINKABLE COUPLING 2. PERMANENT CONNECTION ONLY
		RESISTOFLEX CORPORATION ROSELAND, NJ	22	1. INTERNALLY SWAGED FITTING 2. SEPARABLE CONNECTION ONLY 3. LIP SEAL TYPE SEPARABLE FITTINGS
		ROSAN, INC. NEWPORT BEACH, CA		1. TITANIUM CONSTRUCTION 2. O-RING SEAL
HOSE (INTERIM)	F37404008-0300	TITEFLEX CORPORATION SPRINGFIELD, MA	23	1. PTFE LINER 2. STEEL AND NON-METALLIC REINFORCEMENT BRAIDS
PRESSURE GAGE	1218-63-1	QED/INC. SANTA ANA, CA	24	1. MINIATURE GAGE 2. MULTI-TURN HELICAL BOURDON TUBE
PRESSURE SNUBBER	96239	GAR-KENYON CONTROLS NEW HAVEN, CT	25	1. CONVENTIONAL DESIGN 2. STEEL CONSTRUCTION
PRESSURE TRANSMITTER	18-2143	BENDIX CORPORATION COURTER, INC. BOYNE CITY, MI	25	1. SYNCHRO TYPE (SIMILAR TO MS28005-8) 2. MULTI-TURN HELICAL BOURDON TUBE
QUICK DISCONNECT	AE80943H AE80944H	AEROQUIP CORPORATION JACKSON, MI	23	1. CONVENTIONAL DESIGN 2. THREE DIAMETRAL STATIC SEALS
RELIEF VALVE	1257A 1258	PNEUDRAULICS, INC. MONTCLAIR, CA	18	1. CONVENTIONAL DESIGN 2. ONE DIAMETRAL STATIC SEAL
RESTRICTOR	REFX0380250AB	THE LEE COMPANY WESTBROOK, CT	26	1. 2-WAY RESTRICTOR 2. MULTI-STAGE ORIFICES 3. RATED FLOW: 4 gpm @ 7800 psid 4. TITANIUM CONSTRUCTION
SEALS	SEE SECTIONS 3.1.2 AND 5.1			
SOLENOID VALVE	3321472 (4-WAY VALVE) 3321473 (3-WAY VALVE)	BENDIX CORPORATION ELECTRODYNAMICS DIVISION NORTH HOLLYWOOD, CA	28	1. CONVENTIONAL DESIGN 2. 28 VDC, PILOT OPERATED 3. RATED FLOW: 4-WAY 4.5 gpm 3-WAY 1.4 gpm 4. STEEL HOUSING
TUBING		TRENT TUBE DIVISION CRUCIBLE, INC. FULLERTON, CA		1. 21 Cr-6Ni-9Mn CRES 2. TUBE SIZES: 3/16 X .020 3/8 X .034 1/4 X .023 1/2 X .046

TABLE 2. LHS Fittings Tested

Manufacturer	Description	Part No.	Quantity Tested: Compatibility Test	Quantity Tested: Impulse Test	Quantity Tested: Endurance Test
Deutsch	Tee	DNR10023-080308	1		
Deutsch	Tee	DNR10023-080803		1	
Deutsch	Elbow	DNR11009TE08	4		
Deutsch	Tee	D11056AT03	2		
Deutsch	Tee	DNR11076-08	1		
Resistoflex	Coupling	R44101T-03		1	
Resistoflex	Tee	R44122T-080803	1		
Resistoflex	Elbow	R44129-90T-03		1	
Resistoflex	Tee	R44130T-08	1	1	
Resistoflex	Tee	R44132T-08	2		
Resistoflex	Tee	R44133T-03		1	
Resistoflex	Connector	R44182T-03	1		
Resistoflex	Connector	R44182T-08	4		
Resistoflex	Female Ftg.	R44296T-03	18	2	2
Resistoflex	Male Ftg.	R44298T-03	1		
Resistoflex	Elbow	R44360T-08		1	
Resistoflex	Tee	R45130-030808	1		
Resistoflex	Female Ftg.	R54045T-08	11	3	3
Resistoflex	Female Ftg.	R54045T-03		1	
Resistoflex	Male Ftg.	MR54100T-08	1	1	
Resistoflex	Male Ftg.	MR54100T-03		1	
Raychem	Coupling	3P00101-3	19	2	2
Raychem	Coupling	3P02121-8	2	1	
Rosan	Adapter	RFH5003-18	10		
Rosan	Adapter	RFH5005-18	4		

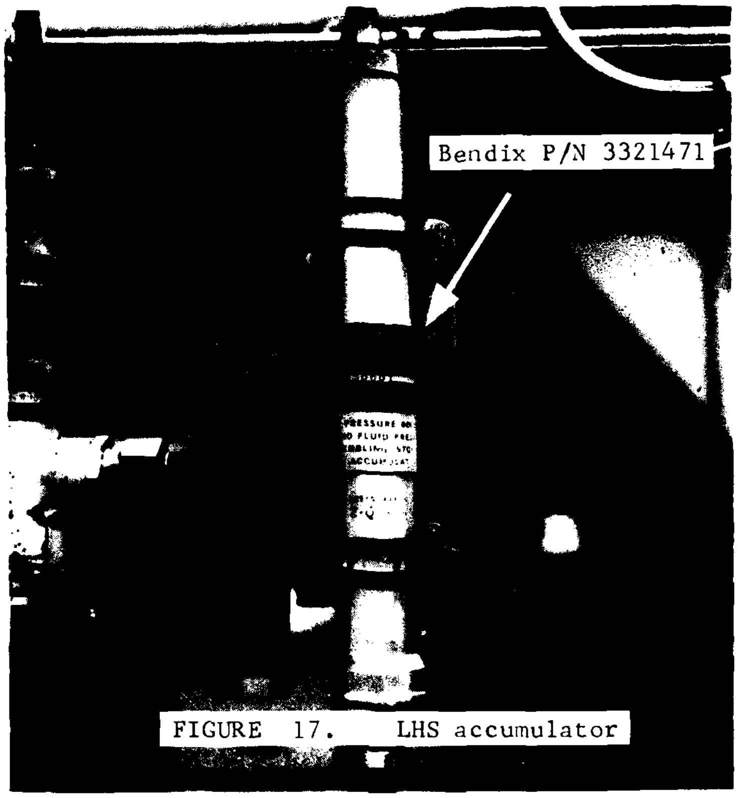


FIGURE 17. LHS accumulator

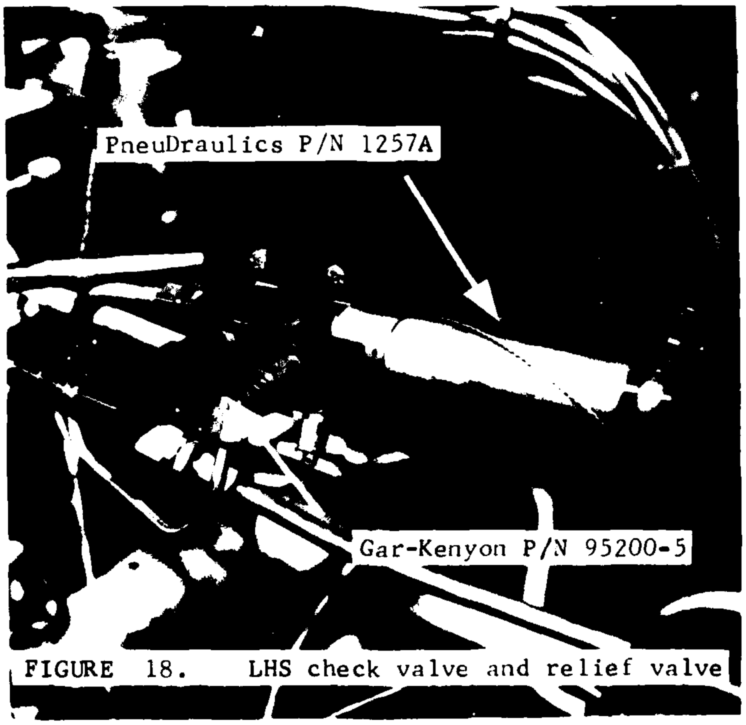


FIGURE 18. LHS check valve and relief valve

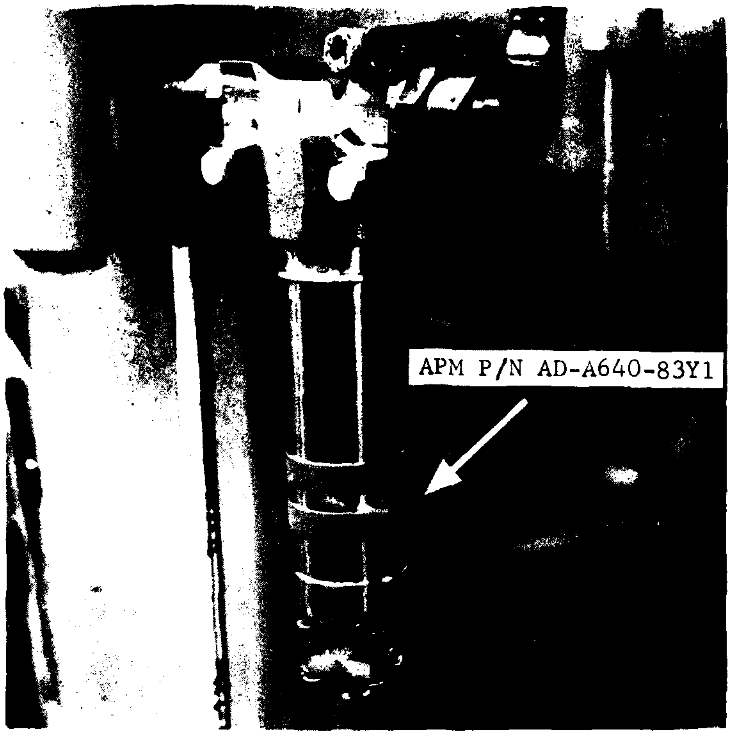


FIGURE 19. LHS filter

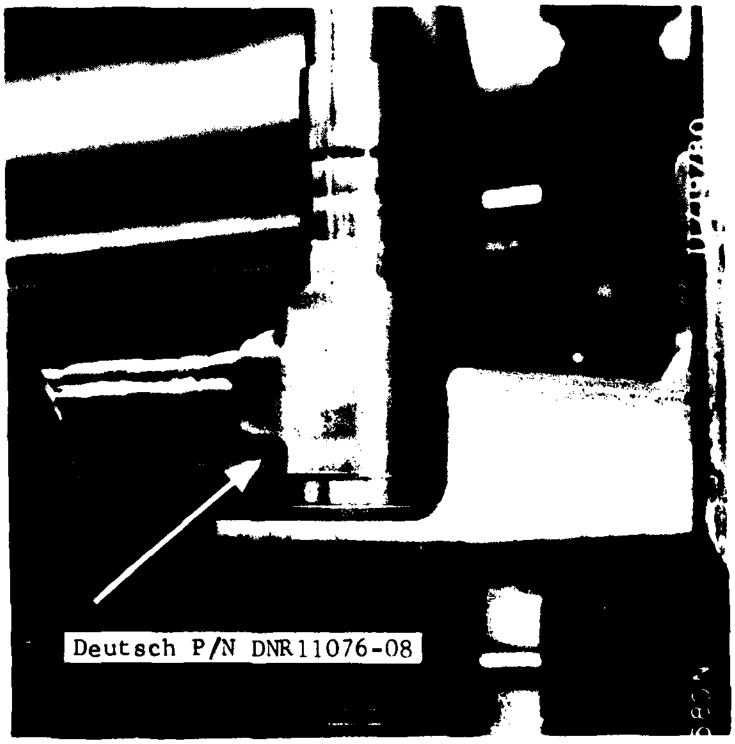


FIGURE 20. LHS fitting (externally swaged)

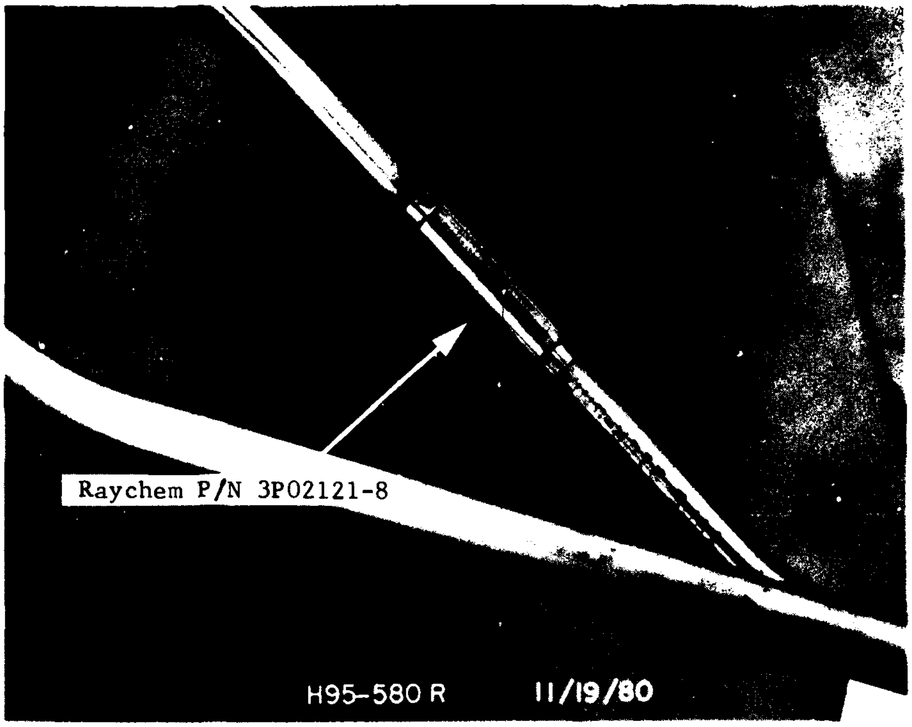


FIGURE 21. LHS fitting (shrink-fit)

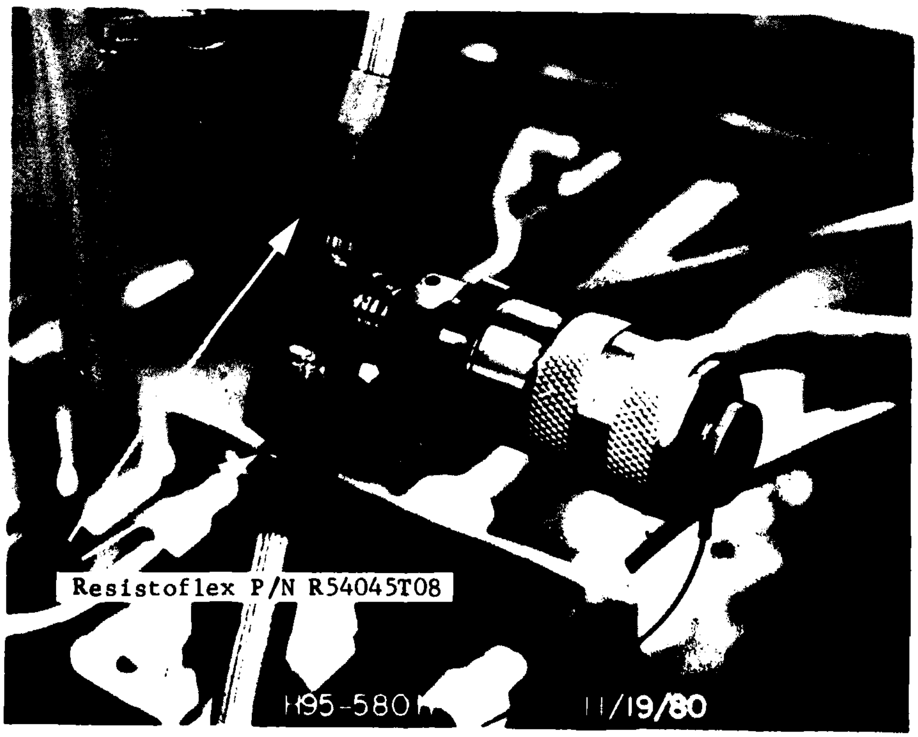


FIGURE 22. LHS fitting (internally swaged)

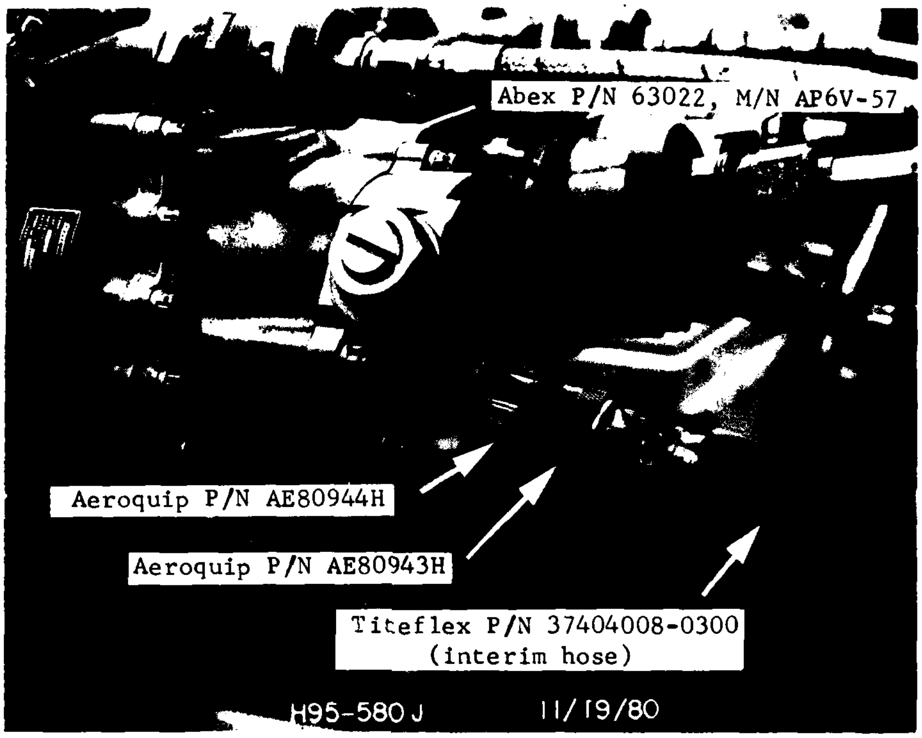


FIGURE 23. LHS hose and quick disconnect

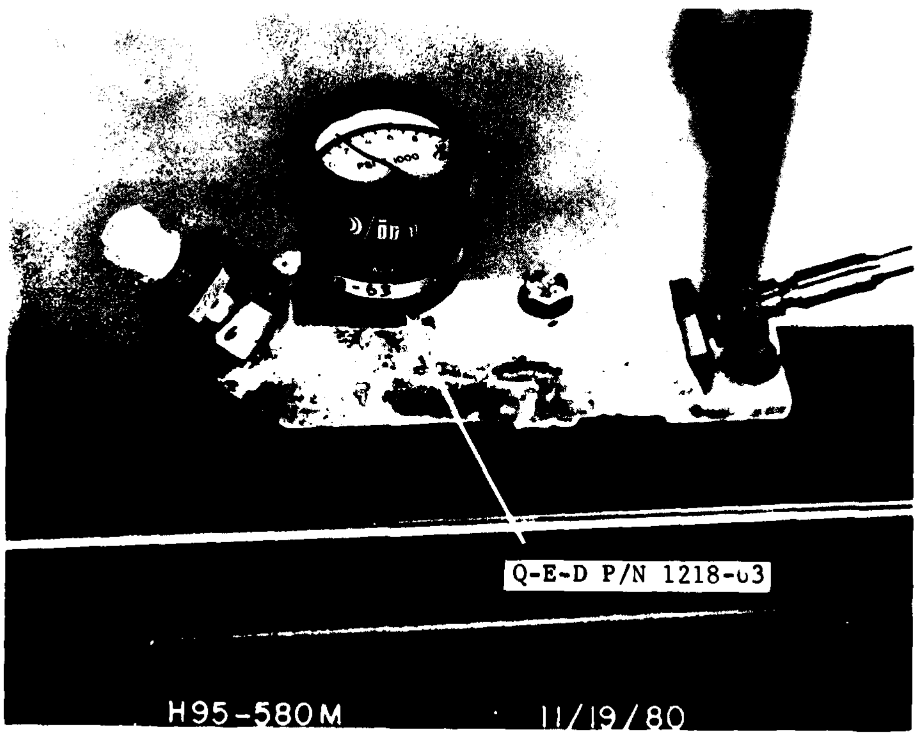


FIGURE 24. LHS pressure gage

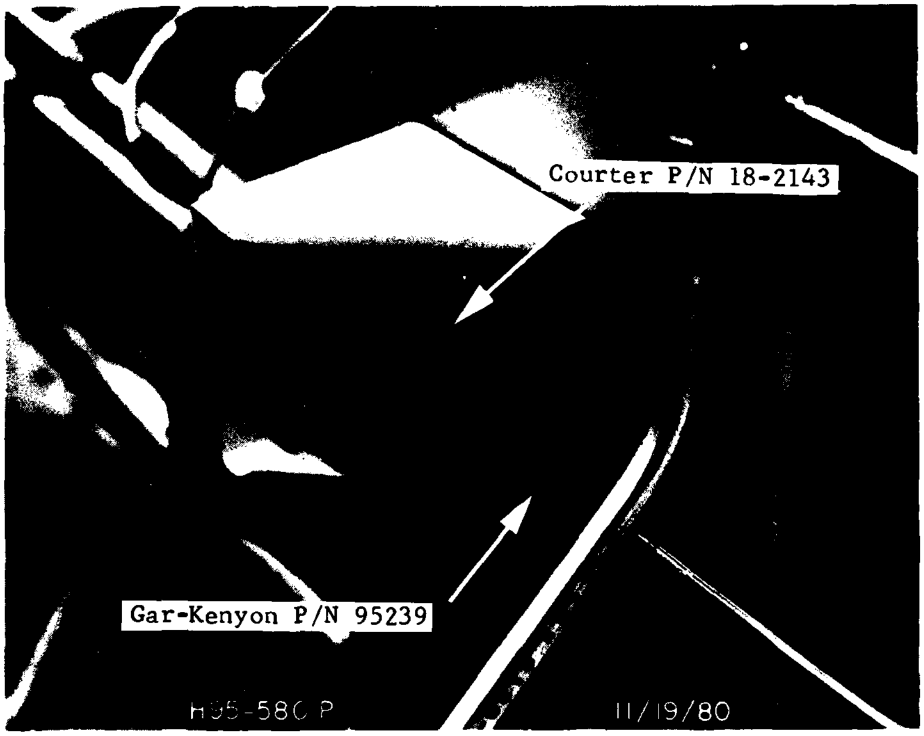


FIGURE 25. LHS pressure transmitter and snubber

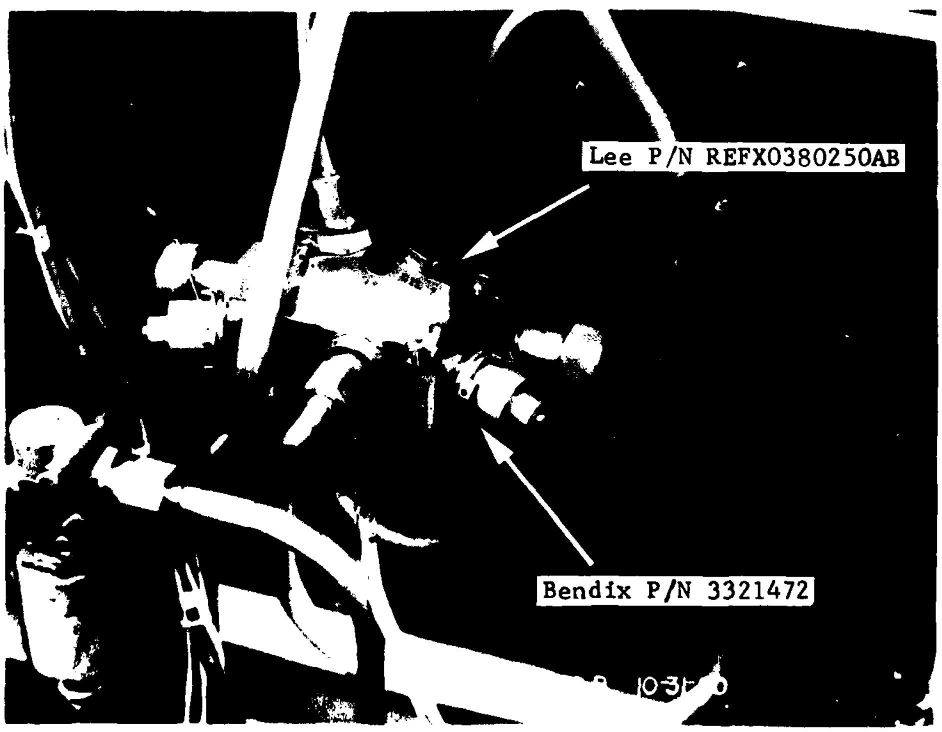


FIGURE 26. LHS solenoid valve and restrictor

4.0 SIMULATOR DESIGN

4.1 ASSEMBLY

The simulator will be a full scale steel structure with LHS component installations and hydraulic distribution systems similar to the flight test aircraft, Figure 27. The simulator is modular in concept for cost effectiveness and program flexibility. Each module is designed to be a removable, yet integral part of the simulator. Two types of modules are employed: 1) power system modules, and 2) actuator load modules.

	Total Number In Test System	Quantity Fabricated In Phase I
Power Modules		
FC-1 System	1	1
FC-2 System	1	1
Load Modules		
Rudder Actuator	1	1
Aileron Actuator	2	1
Spoiler/Deflector Actuator	2	0
UHT Actuator	2	1
Speed Brake Actuator	1	1
Leading Edge Flap Actuator	2	0

The roll feel isolation and AFCS actuators have permanent mounts in the simulator. Details of the modules fabricated in Phase I are presented in section 4.2.

4.2 MODULES

4.2.1 Power Modules

The power system modules have the following components:

FC-1	FC-2
Reservoir	Reservoir
Ground service disconnects	Ground service disconnects
Filters	Filters
Relief valves	Relief valves
Check valves	Check valves
Pressure transmitter/snubber	Pressure transmitter/snubber
Speed brake solenoid valve/ restrictor	Shut-off valve
	Accumulator
	Pressure gage

The components are mounted in the same relative locations as in the flight test aircraft. Transmission line lengths, routing, and clamping in the aircraft are duplicated as nearly as practical in the modules. Pressure and return line diameters are reduced to reflect the lower flow requirements of operating at 8000 psi. Some minor variations in plumbing were necessary to accommodate temperature, pressure, and flow instrumentation. Needle valves were installed to permit operation at low pressures. Photographs of FC-1 and FC-2 modules are presented as Figures 28 and 29.

4.2.2 Load Modules

4.2.2.1 Rudder Actuator - The rudder module utilizes several A-7E components: control valve housing, valve input linkage, structural feedback linkage, and structural load forging. An input control actuator operated by an electro-hydraulic servo valve drives the aircraft linkage, Figure 30. Rudder actuator load is developed by an industrial-type hydraulic cylinder; the load-stroke curve is shown as Figure 31. Actuator swivelling is identical to the aircraft installation. Hydraulic power to the rudder actuator is supplied through 3/16 in. diameter 21-6-9 CRES tubing which flexes as the piston rod strokes.

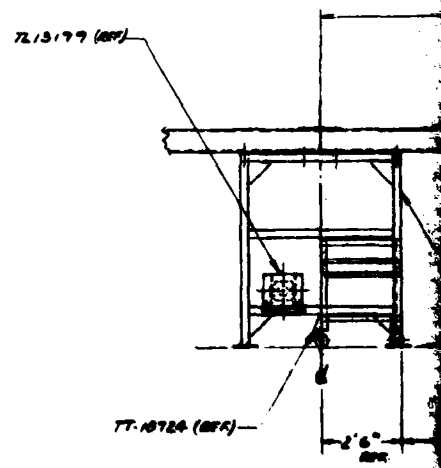
4.2.2.2 Aileron Actuator - The aileron actuator is mounted in a linkage system identical to the aircraft installation, Figure 32. Piston rod travel and actuator body travel combine to deflect a load cylinder producing the load-stroke curve shown on Figure 33. Hoses are used to transmit hydraulic power to the actuator. The input lever on the aileron actuator is controlled by a servo actuator operating at 500 psi.

4.2.2.3 UHT Actuator - The UHT actuator mounting and swivelling are identical to the aircraft installation, Figure 34. Control of the valve input lever is through an A-7 linkage system which includes structural feedback. Actuator loading is developed when an industrial-type cylinder is moved away from a neutral position, Figure 35. Hydraulic power is supplied through 1/4 diameter 21-6-9 CRES tubing which flexes as the UHT actuator strokes.

The UHT input linkage system is operated by an AFCS pitch actuator mounted on the UHT module as shown on Figure 36. The output linkage of the AFCS actuator was modified to provide sufficient travel to drive the UHT actuator full stroke. A bungee was installed to prevent overloading the UHT actuator input linkage.

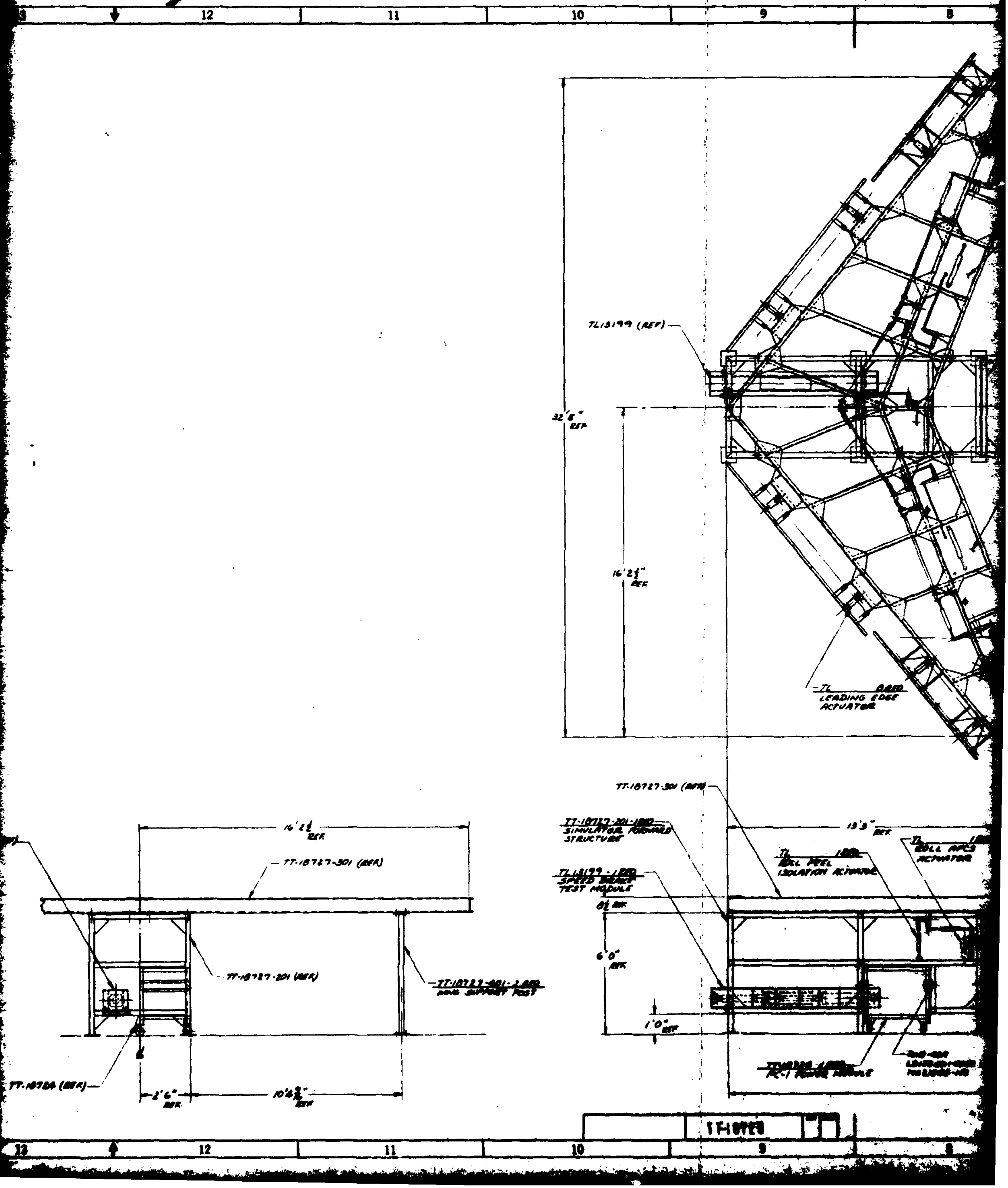
An 8000 psi direct-drive control valve operated the AFCS actuator, Figure 36. The electronic drive unit used to power the valve torque motor is shown on Figure 37. The direct-drive valve and electronic package are discussed in section 3.1.2.

16 15 14 13 12

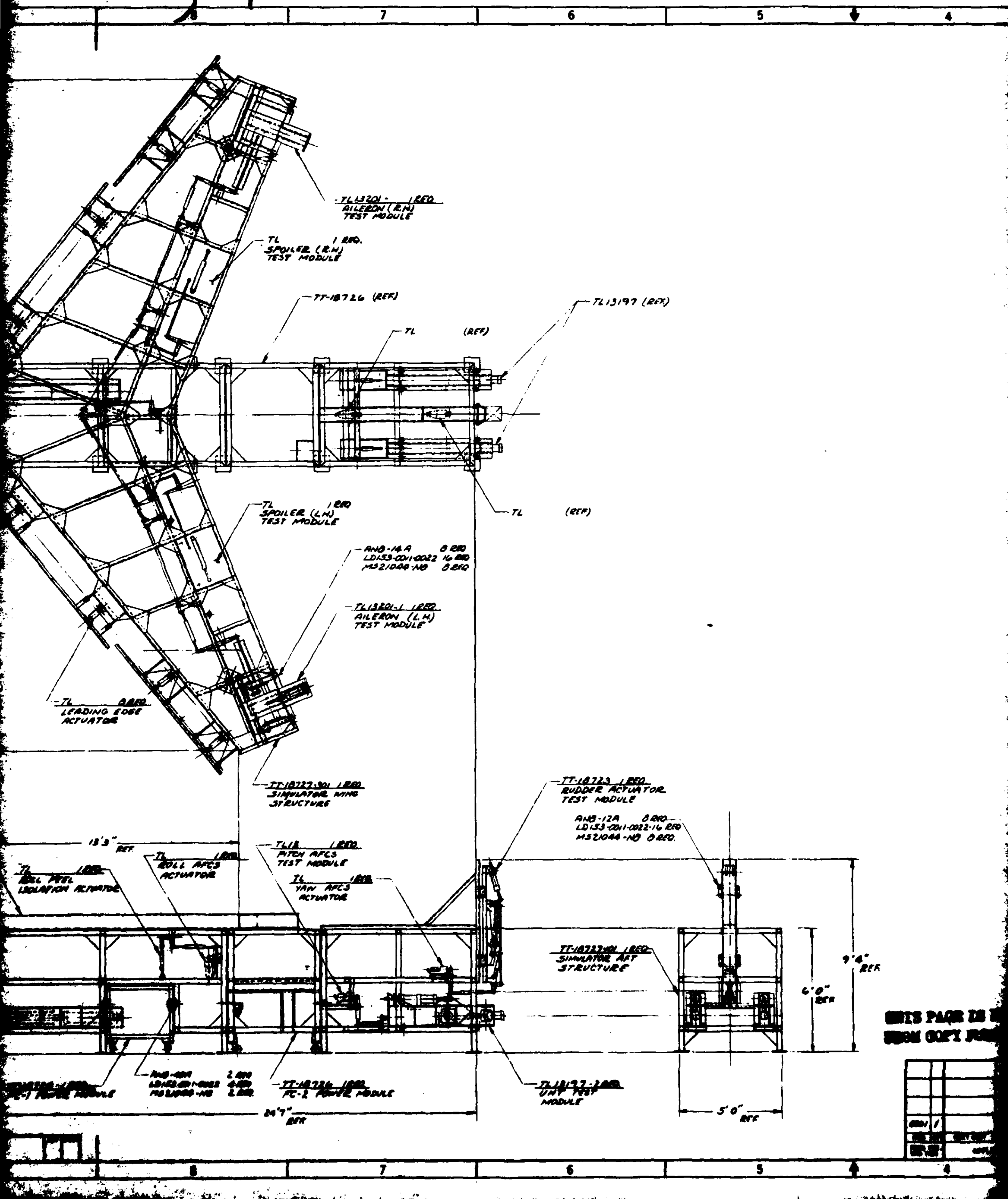


16 15 14 13

2



TL13199 (REF)
32'8" REF
16'2¼" REF
LEADING EDGE ACTUATOR
TT-18727-301 (REF)
TT-18727-201-1 ARD SIMULATOR FORWARD STRUCTURE
TL13199-1 ARD SPEED BRAKE TEST MODULE
13'3" REF
ROLL FEEL ISOLATION ACTUATOR
ROLL APCS ACTUATOR
8½ REF
6'0" REF
1'0" REF
AC-1 POWER MODULE
16'2½ REF
TT-18727-301 (REF)
TT-18727-201 (REF)
TT-18727-401-1 ARD WING SUPPORT POST
TT-18724 (REF)
2'6" REF
10'6⅝" REF
TT-18728



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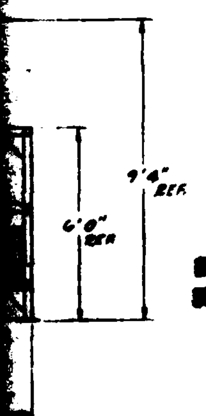
REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
		1. MAY BE REWORKED 2. CANNOT BE REWORKED 3. RECORD CHANGE 4. NEW SHOP PRACTICE 5. PARTS MADE ON		

4

FIGURE 27

QTY REQ	PART NO.	NOMENCLATURE
8	TL	LEADING EDGE ACT.
1	TL	ROLL FEEL ISO ACT.
1	TL	ROLL AFCS MODULE
1	TL	YAW AFCS MODULE
1	TL	PITCH AFCS MODULE
1	TL	SPOILER ACT. MODULE
1	TL	SPOILER ACT. MODULE
1	TL13201-	AILERON ACT. MODULE
1	TL13201-	AILERON ACT. MODULE
1	TL13199	SPEED BRAKE MODULE
2	TL13197	UHT ACT. MODULE
2	TT-18727-401	SIMULATOR-WING POST
1	TT-18727-301	SIMULATOR-WING SECT
1	TT-18727-201	SIMULATOR-FWD SECT.
1	TT-18727-101	SIMULATOR-AFT SECT.
1	TT-18726	FC-2 POWER MODULE
1	TT-18724	FC-1 POWER MODULE
1	TT-18723	RUDDER ACT. MODULE

PARTS LIST



NOTES: UNLESS OTHERWISE NOTED

0001	1		4808696	TEST	
APPLICATION				EFFECTIVITY	

FINISH: NONE

HEAT TREAT: NONE

DO NOT SCALE PRINT

SIMULATOR ASSEMBLY LIGHTWEIGHT HYDRAULIC SYSTEM

SIZE	CODE IDENT NO.	
J	89372	TT-18728

TT-18728

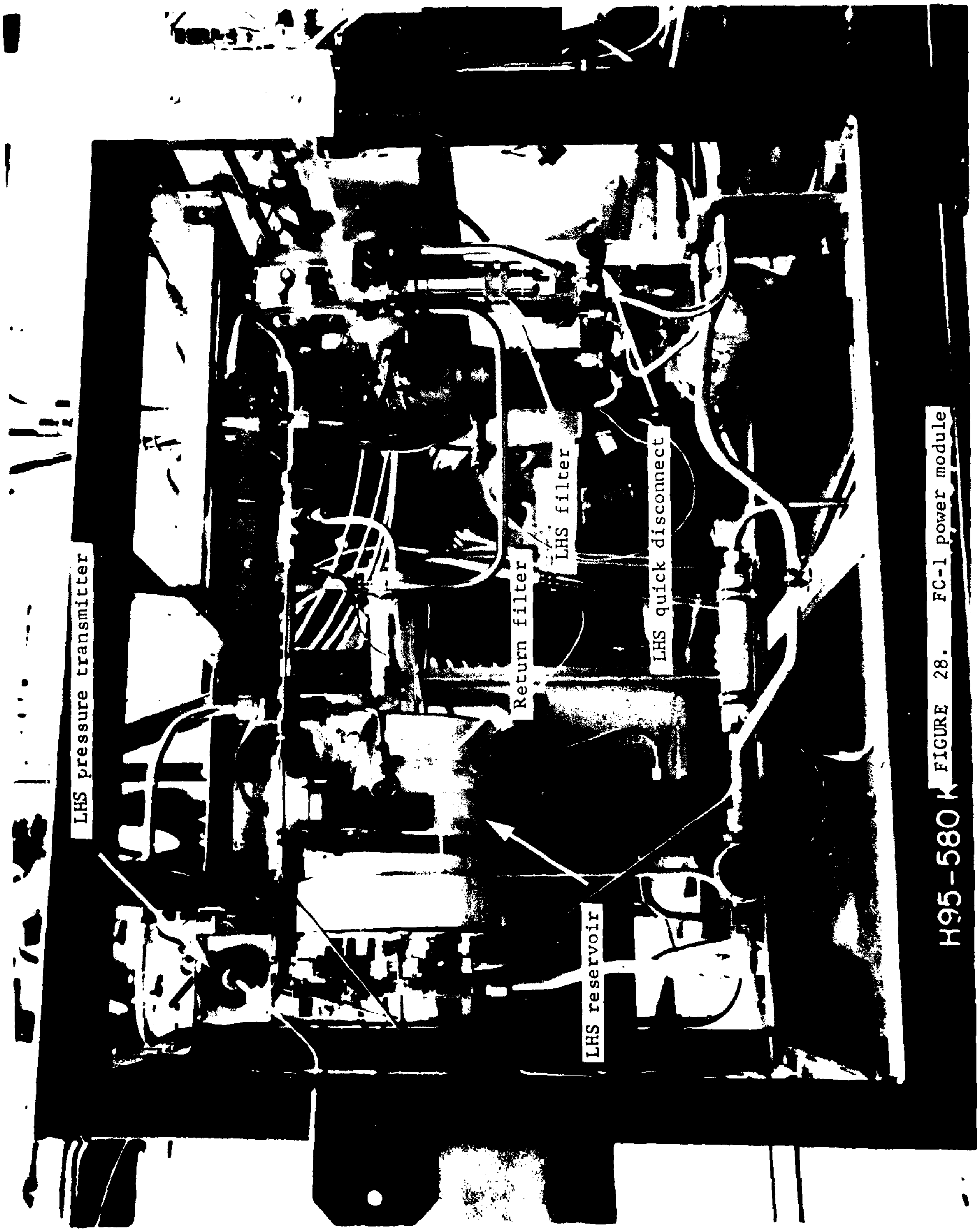


FIGURE 28. FC-1 power module

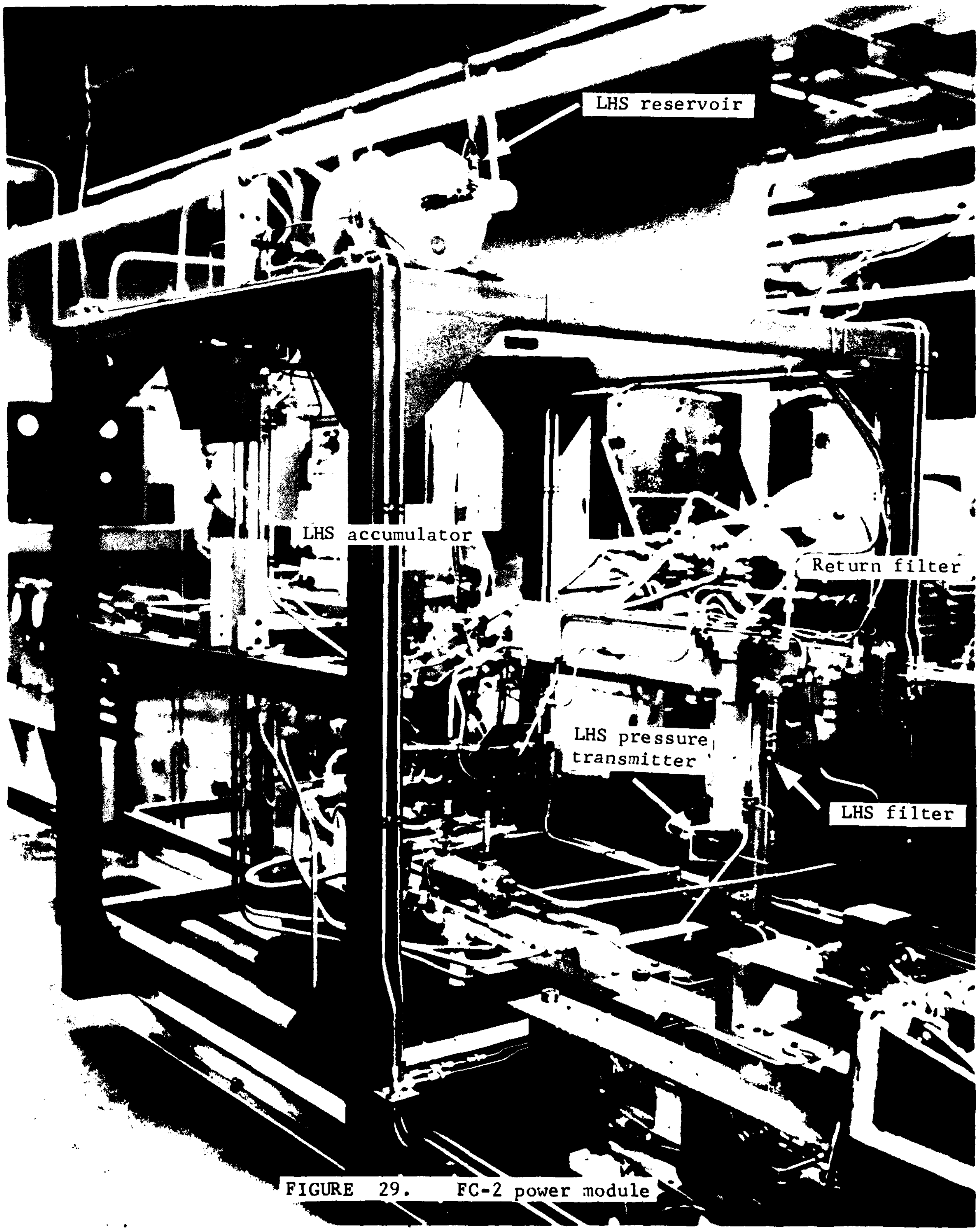


FIGURE 29. FC-2 power module

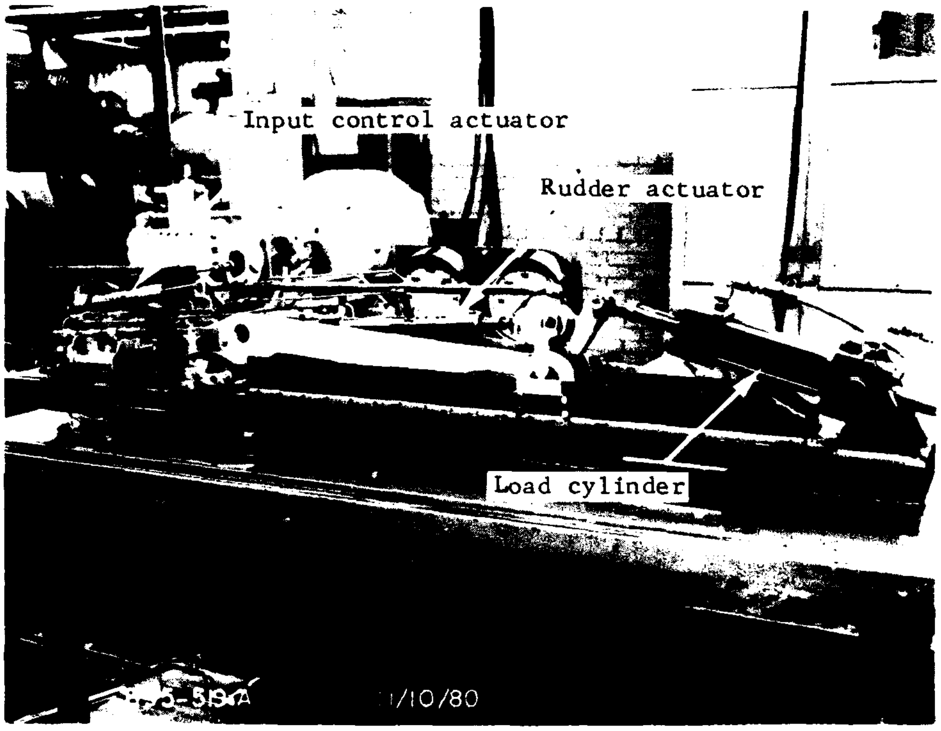


FIGURE 30. Rudder actuator module

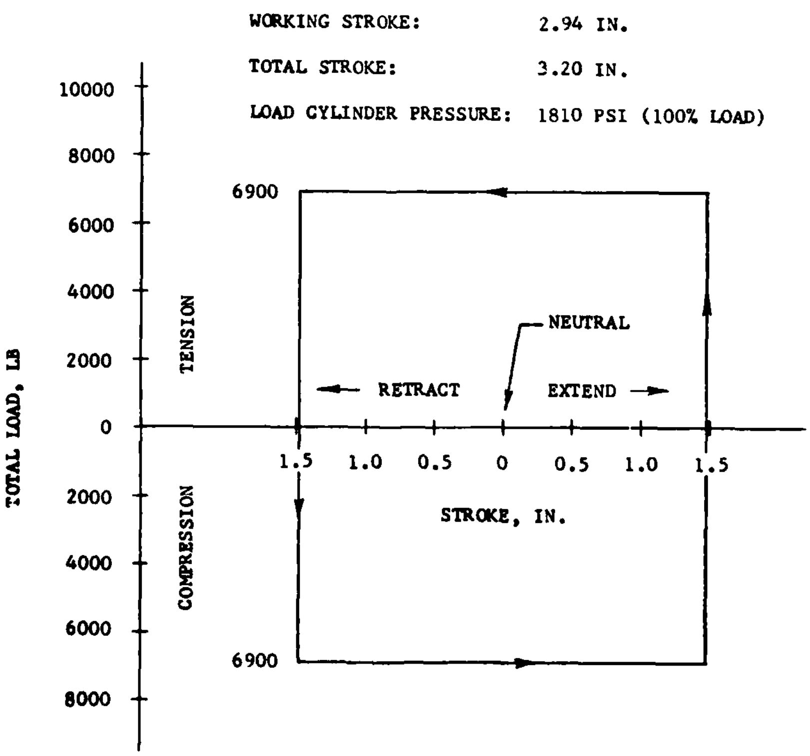


FIGURE 31. Rudder actuator load/stroke curve

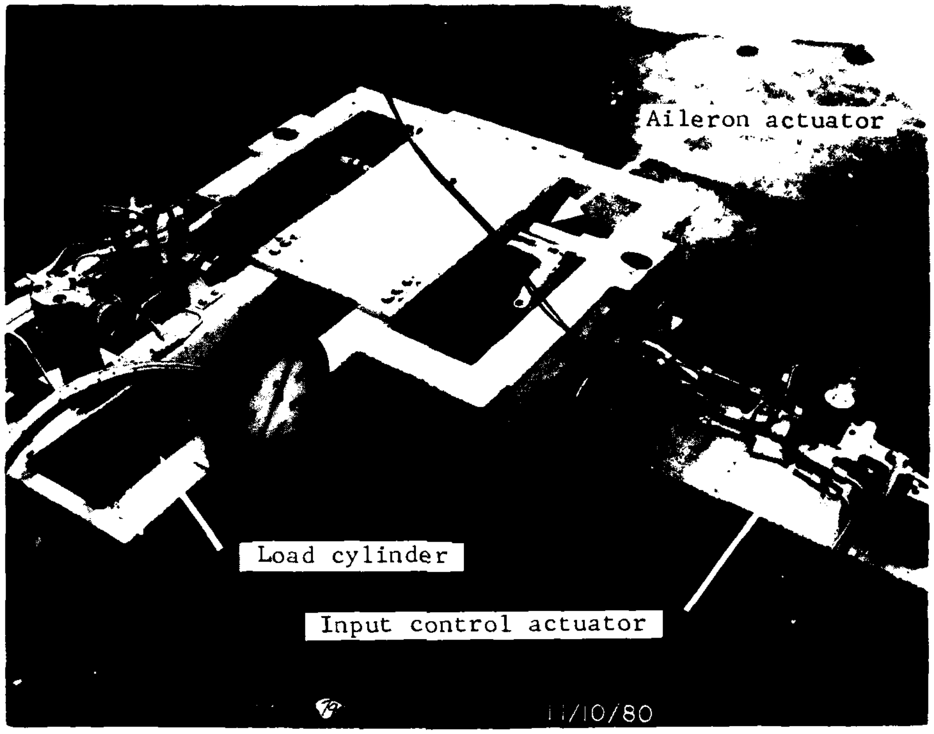


FIGURE 32. Aileron actuator module

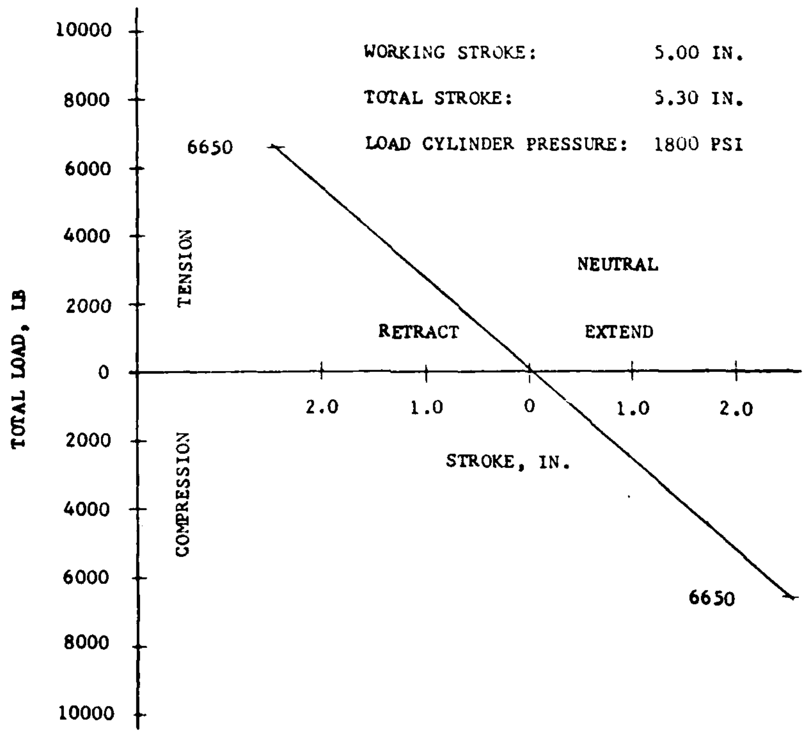
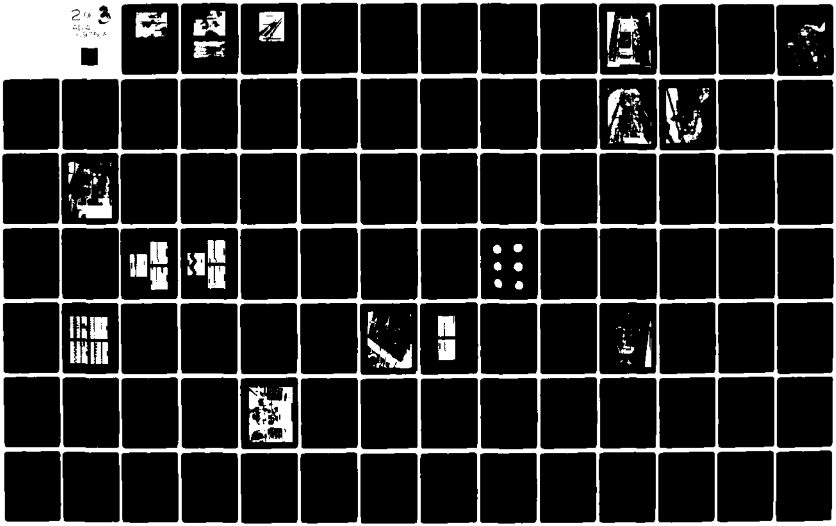


FIGURE 33. Aileron actuator load/stroke curve

AD-A097 505 ROCKWELL INTERNATIONAL COLUMBUS OH NORTH AMERICAN AI--ETC F/G 13/7
DESIGN, DEVELOPMENT, AND EVALUATION OF LIGHTWEIGHT HYDRAULIC SY--ETC(U)
JAN 81 J N DEMARCHI, R K HANING N62269-78-C-0363
UNCLASSIFIED NR81H-2 NADC-77108-30 NL

2 OF 3



A
9750

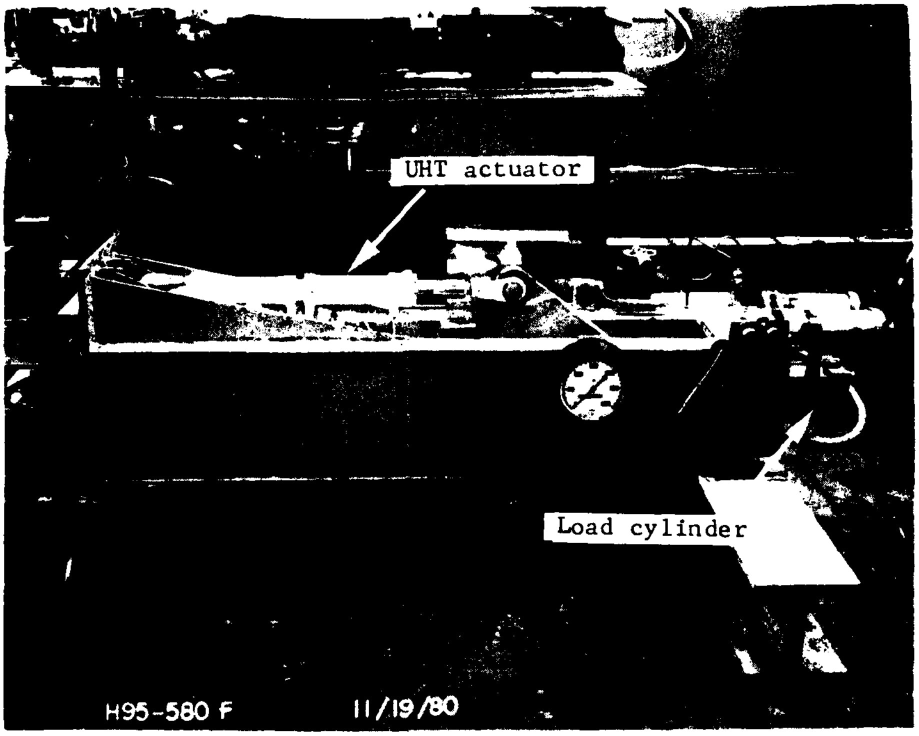


FIGURE 34. UHT actuator module

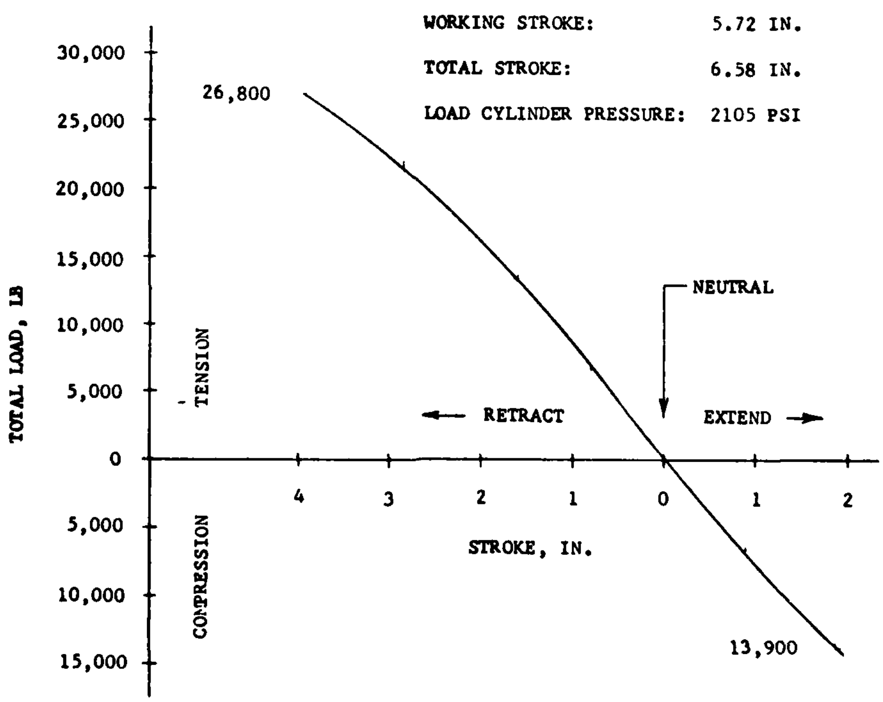


FIGURE 35. UHT actuator load/stroke curve

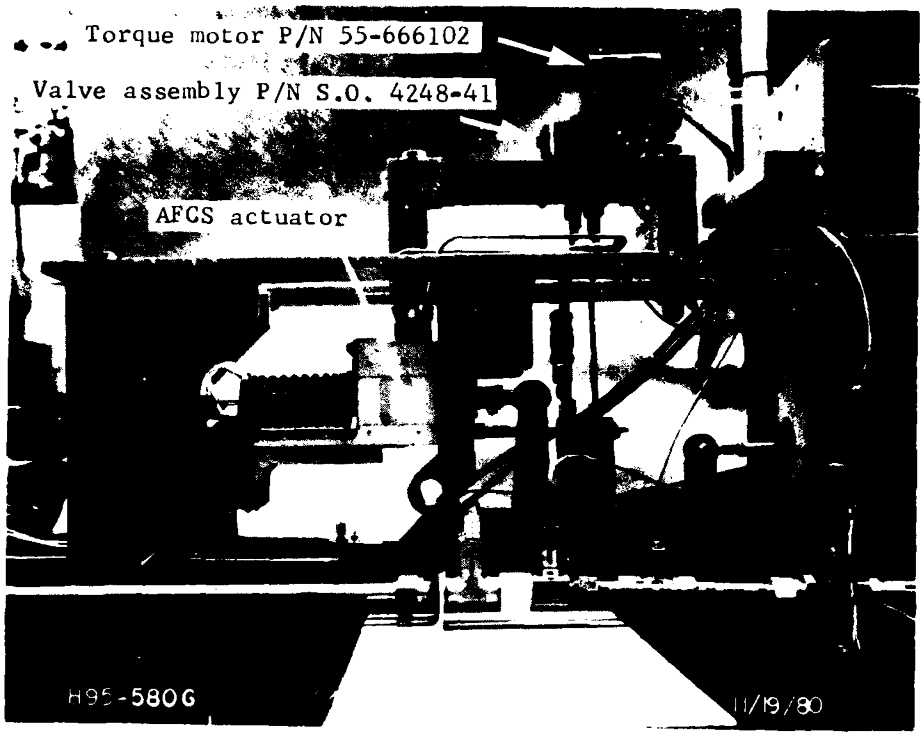


FIGURE 36. AFCS actuator

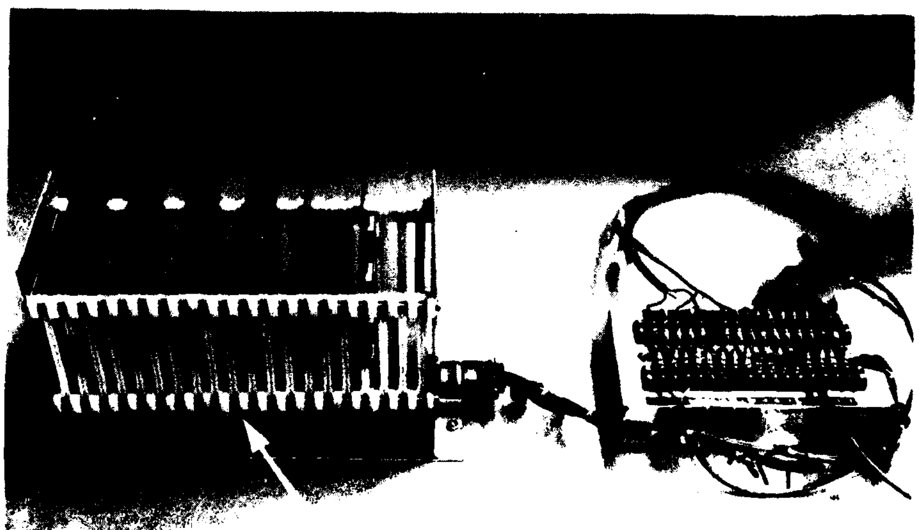


FIGURE 37. Electronic drive unit

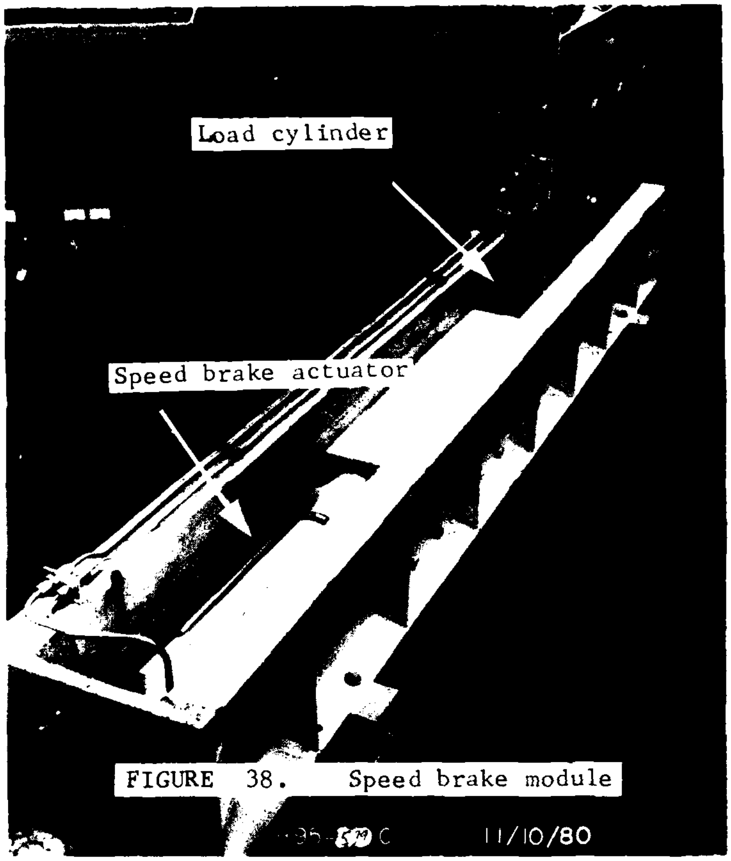


FIGURE 38. Speed brake module

WORKING STROKE:	19.94 IN.
TOTAL STROKE:	19.94 IN.
LOAD CYLINDER PRESSURE:	2040 PSI (100% LOAD)

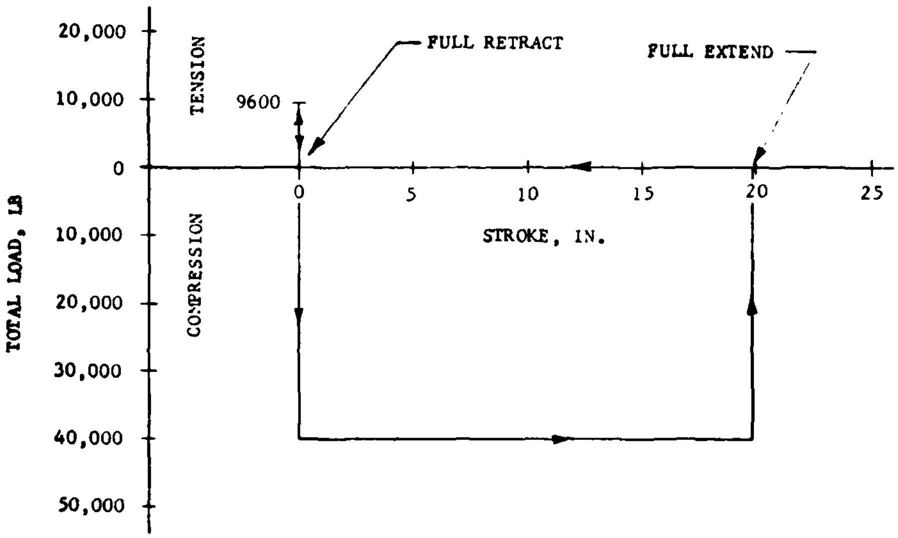


FIGURE 39. Speed brake load/stroke curve

4.2.2.4 Speed Brake Actuator - The swivelling motion of the A-7 speed brake actuator requires a minimum vertical height of 75 inches. Space constraints in the ground simulator, Figure 27, prohibited duplicating the aircraft geometry and swivelling of the speed brake actuator. Therefore, by necessity, swivelling motion in the speed brake load module was modified to eliminate ground interference.

The speed brake actuator is loaded by an industrial cylinder as shown in Figure 38, and is controlled by a 4-way solenoid valve located on the FC-1 power module. The load/stroke curve is given on Figure 39. A restrictor in the 4-way valve limits speed brake piston velocity to maintain system pressure.

5.0 COMPONENT TESTING

5.1 SEAL DEVELOPMENT

5.1.1 Introduction

The selection of rod seals is recognized as critical to the successful demonstration of reliability in a lightweight hydraulic system. The rod seal in contemporary aircraft is the most likely source of external leakage. External leakage is, in turn, the most frequently cited cause of actuator removals.

A study was conducted to select candidate rod seals for use in the LHS test actuators. The investigation considered single stage seals and two stage unvented seals.

Information presented in Section 5.1 was condensed from Vought Report 2-51700-C/9R-52140, Reference 16.

5.1.2 Seal Selections

A 200 hour seal test was completed by NAAD-Columbus for the LHS program shortly before the rod seal study was initiated, Reference 10. The Bal Seal, which was a part of that test, appeared to have the least wear at the conclusion of testing. Therefore, the Bal Seal was selected to be tested in both a single and a two stage seal configuration. The Bal Seal has two negative aspects which must be considered:

(1) It is relatively inflexible and requires a split groove for installation.

(2) It has a relatively large cross section; therefore, the groove must be deeper than that of a groove designed in accordance with MIL-G-5514.

The two seal configurations using the Bal Seal are shown in Figure 40. The seal tested by NAAD was a heavy duty unit having a cross-section height of 1/4 inch. Vought tested a medium duty seal which had a 3/16 inch cross section. Bal Seal Engineering Company recommended that a polyimide backup ring be included in the seal; this feature was not a part of the seal tested by NAAD.

Republic Aircraft Corporation performed a number of seal test programs for the USAF in the 1958 era. One of these programs evaluated seals at temperatures from +300 to +325°F where Teflon backup rings become very soft and tend to flow or creep. It was reported that two backup rings on the low pressure side of the elastomer repeatedly gave a five-fold increase in seal life as compared to a single backup ring. Seals designated "E-2", "B", and "D" in Figure 40 make use of the two backup ring concept in an attempt to close the extrusion gap. The backup rings are all uncut. Materials and seal suppliers are identified in Table 3.

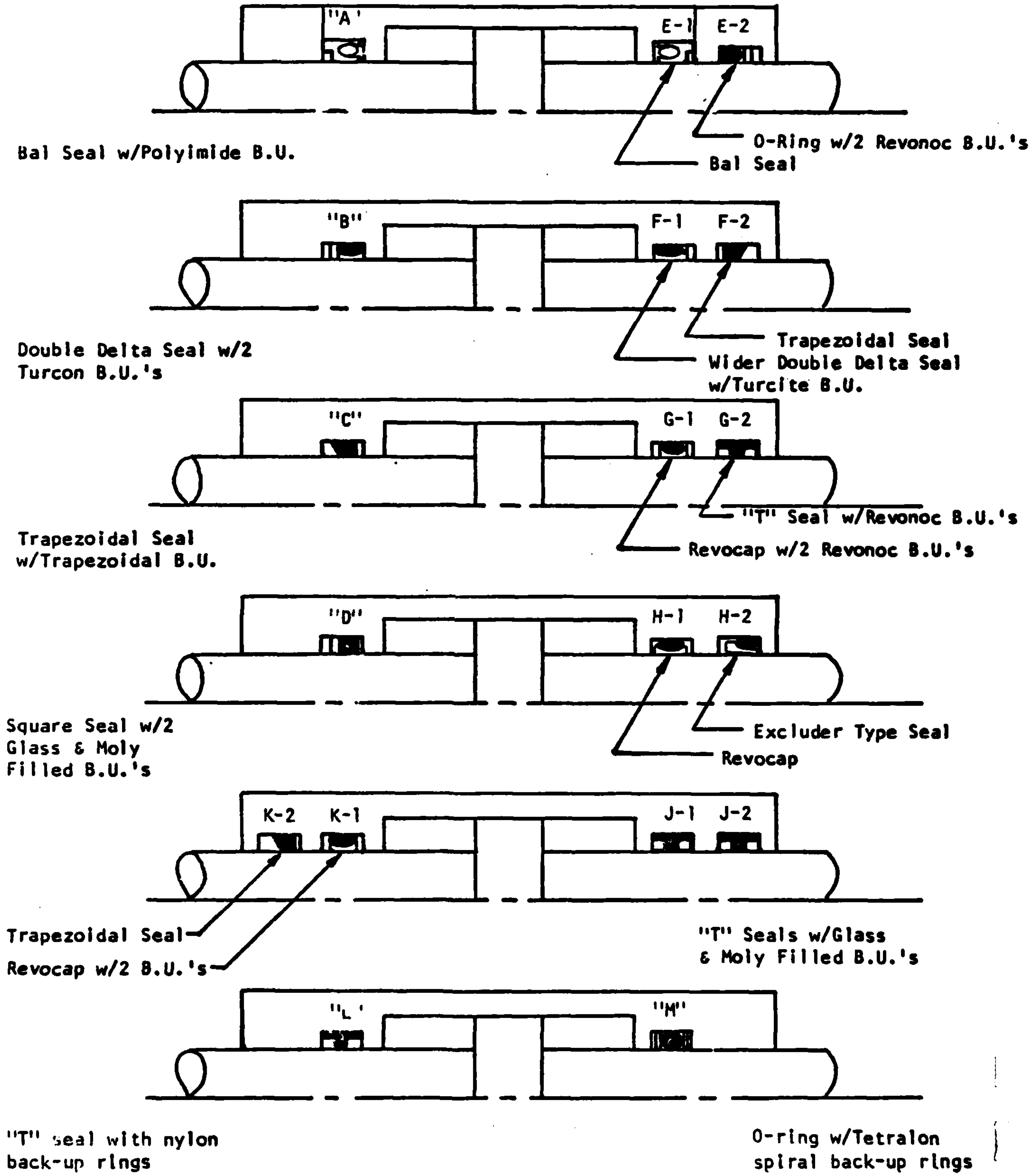


FIGURE 40. Seal configurations tested

TABLE 3. Seal Materials and Suppliers

	SUPPLIER	MATERIALS
Seal A	Bal Seal Engineering Co.	back-up ring - polyimide seal - graphite filled Teflon
Seal B	Shamban - back-up rings Shamban - double delta Conover - O-ring	glass/moly filled Turcon 33012 glass/moly filled Turcon 33012 MIL-P-83461 compound
Seal C	Conover	back-up ring - Revonoc 18158 elastomer - MIL-P-83461
Seal D	Conover	back-up rings - Revonoc 18158 elastomer - MIL-P-83461
Seal E-1	Bal Seal Engineering Co.	back-up ring - polyimide seal - graphite filled Teflon
Seal E-2	Conover	back-up rings - Revonoc 18158 O-ring - MIL-P-83461
Seal F-1	Shamban Shamban	double delta - glass/moly filled Turcon 33012 back-up ring - Turcite 79
Seal F-2	Conover	back-up ring - Revonoc 18158 elastomer - MIL-P-83461
Seal G-1	Conover	Revocap - Revonoc 6200 back-up rings - Revonoc 18158 O-ring - MIL-P-83461
Seal G-2	Conover	back-up rings - Revonoc 18158 elastomer - MIL-P-83461
Seal H-1	Conover	Revocap - bronze filled Revonoc 5300 O-ring - MIL-P-83461
Seal H-2	Shamban Conover	Excluder - bronze filled Turcon O-ring - MIL-P-83461
Seal K-1	Conover	Revocap - Revonoc 6200 back-up rings - Revonoc 18158 O-ring - MIL-P-83461
Seal K-2	Conover	back-up ring - Revonoc 18158 elastomer - MIL-P-83461
Seal J-1	Greene Tweed	back-up ring - glass/moly filled Teflon "T" elastomer - ?
Seal J-2	Greene Tweed	same as J-1
Seal L	Greene Tweed	back-up ring - nylon "T" elastomer - ?
Seal M	Royal Industries Conover	Spiral back-up ring - Tetralon 700 O-ring - MIL-P-83461 compound

Seal "C", "K-2", and "F-2" in Figure 40 are referred to as a trapezoidal seal. Both the backup ring and the elastomer have a trapezoidal cross-section. Under pressure, the elastomer produces a force vector which pushes the backup ring toward the extrusion gap. This Vought design is an outgrowth of a seal problem experienced on a rocket motor several years ago. The trapezoidal backup ring provides a thick cross section at the extrusion gap and has proven to be very resistant to extrusion.

The seal combination "G-1" and "G-2" shown in Figure 40 is similar to that selected by Rockwell International for the B-1 bomber except that a vent to return was provided in the B-1 seal configuration.

Seal "H-1" shown in Figure 40 was a cap strip designed for a no backup width groove. Two spacer backup rings were installed on the upstream side of the seal to prevent the cap strip/O-ring seal from being loose in the two backup width groove. The "H-2" seal is a scraper/seal which is like that used by Vought on S-3A utility actuators, except that it was made from different materials. The scraper/seal is primarily designed as a scraper. It had been determined, however, to function as a seal to at least 4500 psi if the retaining lip diameter was no more than 0.012 inch larger than the rod. A similar arrangement is used in a number of industrial cylinders. The "H-1/H-2" configuration provides a form of two stage seal in the space which would normally be needed for a single seal and scraper.

The square seal "D" shown in Figure 40 was selected because it would experience little change in shape between the pressurized and unpressurized state. This criterion of minimum change in shape came from the tear down of cylinders at the end of the NAAD tests, Reference 10. It was hypothesized that this wear might have been fretting of the rubber caused by repeatedly changing its shape when pressure was applied and relieved.

Seal "F-1" in Figure 40 is a double delta seal designed for a one backup width groove. Two seal suppliers were of the opinion that this would wear better than the cap strip designed for a no backup width groove. A Turcite backup ring was used to give greater extrusion resistance.

Seals shown as "K-1/K-2", "J-1/J-2", and "L" were not a part of the original test. These configurations received limited cycling as replacements for seals which failed.

5.1.3 Test Procedure

5.1.3.1 Test Actuators - Four test actuators were required for the program. The most economical way of fabricating these actuators was to use parts from industrial cylinders. The cylinders of several manufacturers were reviewed to determine which designs would most readily adapt to special end caps fabricated to house the candidate seals. An Ortman-Miller design was selected: model 3TH, mounting style DH, 1.5 in. bore, 1 in. rod, and 4 in. stroke. The four test cylinders are shown in Figure 41.

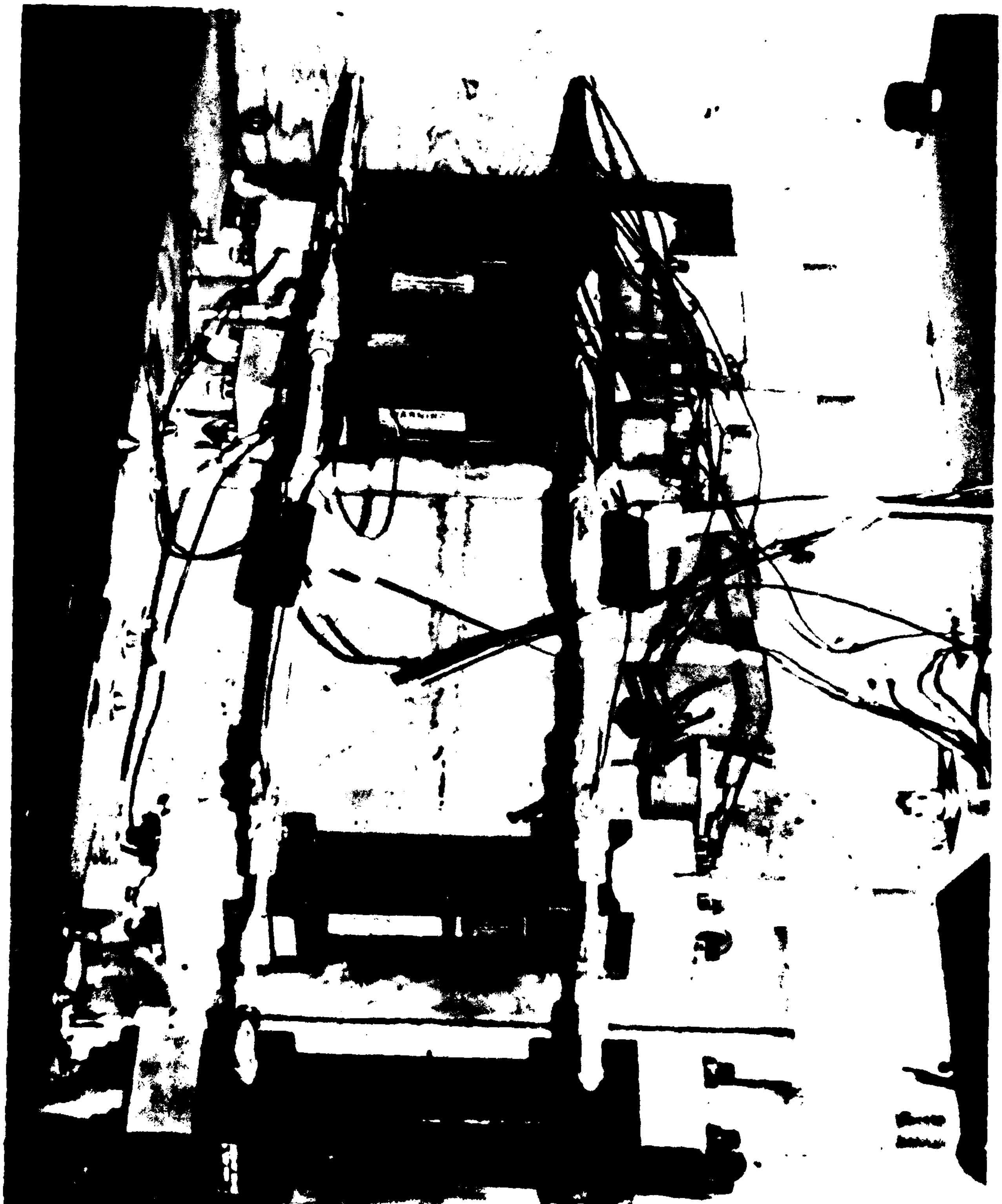


FIGURE 41. Rod seal test cylinders

5.1.3.2 Test Fixture - A fixture was designed with a large bellcrank to which each of the four test cylinders was attached. This assured that each cylinder stroked at the same velocity and displacement. A schematic of the fixture is shown on Figure 42. Figure 43 is a photograph of the test setup. Each of the test cylinders had an output force capability of 7,854 pounds at 8000 psi. The actual load selected was 80% of the maximum load. This force was reacted by one large load cylinder mounted on the centerline of the test fixture.

The control system used an electro-hydraulic actuator to stroke a mechanical input valve sinusoidally, see section 5.1.4. Flow from the mechanical input valve was directed to each of the four test cylinders simultaneously. The follow-up position of the cylinders was fed back to a summing linkage which compared the commanded input with the output positions to create an error signal. Since the actuators were plumbed in parallel, each actuator was subjected to the same differential pressure.

5.1.3.3 Test Cycling and Data - The cycling schedule was as follows:

- 8 test blocks of 50 hours each (400 hours total)
- 90% of cycling at a stroke of ± 1.75 inches
- 10% of cycling at a stroke of ± 0.10 inch
- Seal temperatures were approximately +250°F except during warm-up periods

Specific data taken on the seals included:

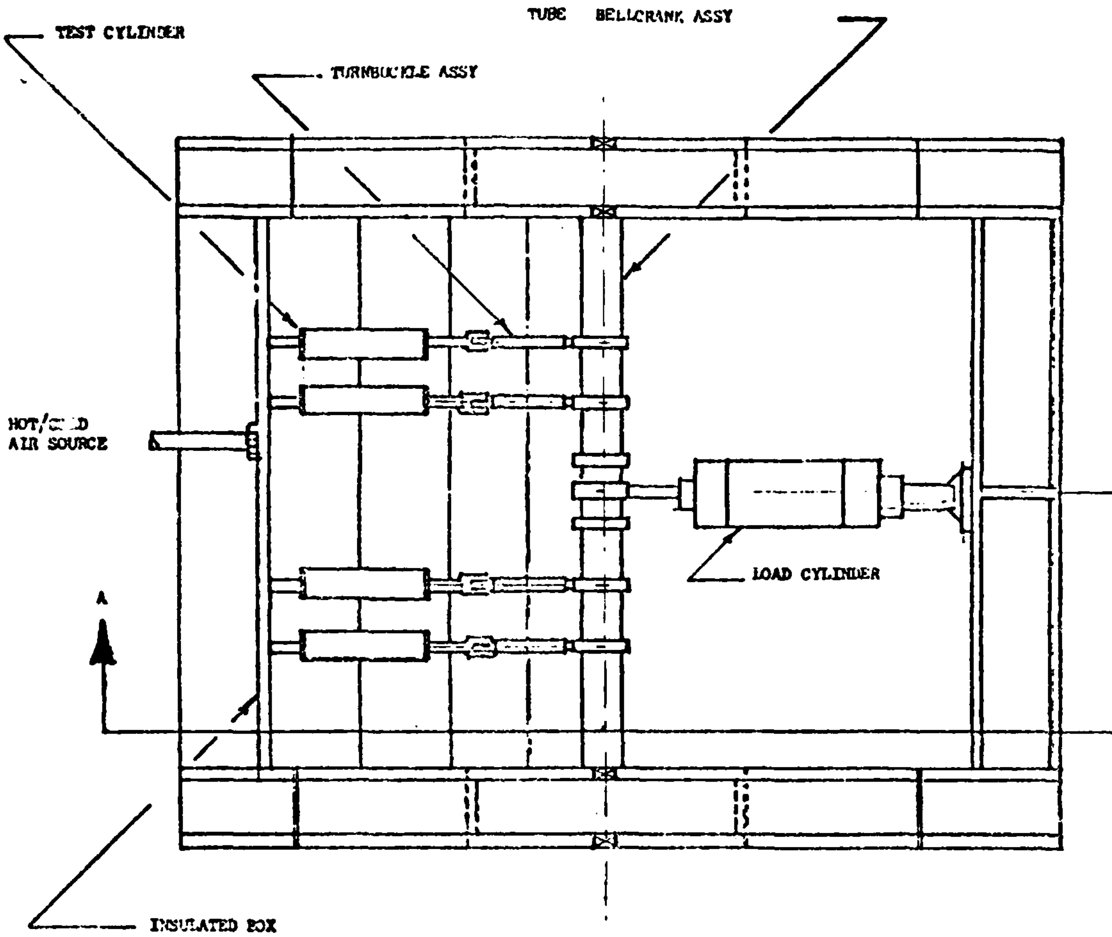
(1) Static leakage was measured at start of the test and at the end of each 50 hour test block. Leakage was measured at -40°F and at 250-275°F with pressures of 8000, 100, and 1 psig.

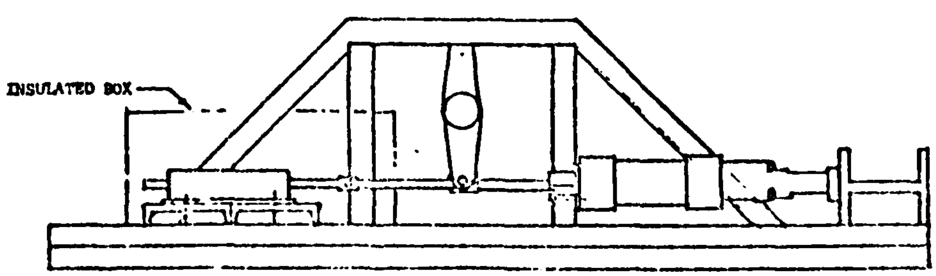
(2) Dynamic rod seal leakage was collected continuously throughout the test. This leakage was then measured and divided by the number of cycles to obtain the leakage rate.

(3) The pressure between stages of the two stage seals was monitored until it built up to 5000 psi--the rating of the gages. At this point, the gages were shut off.

(4) During the last 150 hours of the test, static leakage checks were made on the 1st stage of each two stage seal at one week intervals. This roughly coincided with the 50 hour test block.

The test accumulated a total of 172,618 full stroke and load cycles and 80,076 cycles of 10% stroke. While the test was far less than the number of short stroke cycles normally imposed during qualification of a flight control actuator, there were considerably more than the usual 50,000 full stroke cycles which form a part of the 2,000,000 cycle spectrum of MIL-C-5503C. Long-stroke cycling is more damaging to seals than short-stroke cycling. Furthermore, the 10% stroke cycles were run under design load conditions rather than under a 10% loading as specified by MIL-C-5503.





VIEW A-A

FIGURE 42. Seal test fixture schematic

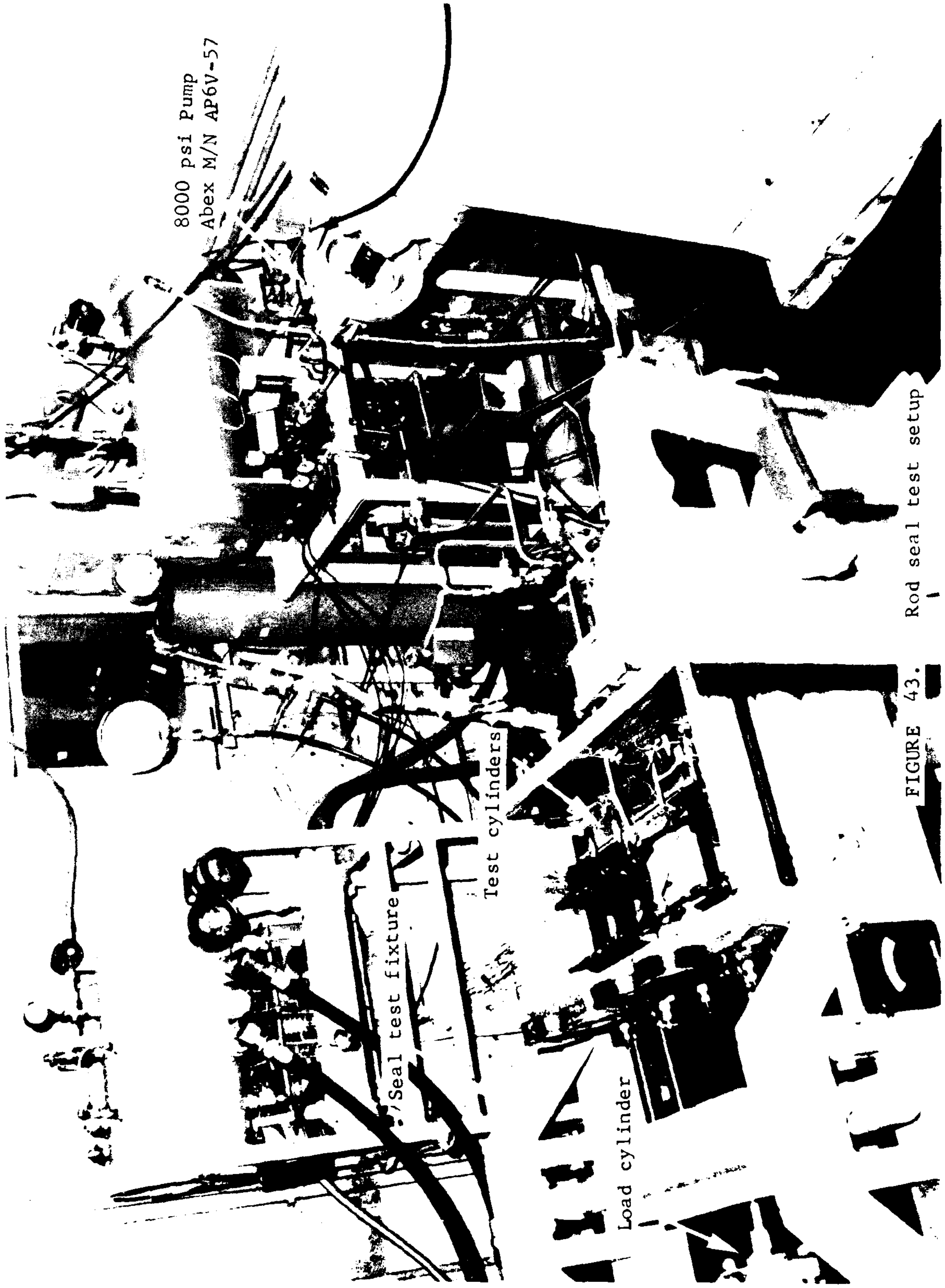


FIGURE 43. Rod seal test setup

5.1.4 Test Results

The rod seal study was 410.2 hours in duration. Testing was started with eight seal configurations. Five of the eight completed the test with acceptable leakage rates using the allowable 1 drop/25 cycle criterion. Four additional seal configurations saw limited testing as replacements for failed seals. A summary of the seal test results is given on Table 4. Eight diametral type static seals were incorporated in the test actuators where the end caps mate with the cylinder barrel; all of these seals performed satisfactorily.

A detail analysis of seal failures and seal condition was made at the end of the test. The following conclusions were reached:

(1) Reliable long life rod seals can be attained for 8000 psi systems.

(2) Rubber against the rod wears well if protected properly. The backup ring and the extrusion gap are key elements in determining elastomer wear. The extrusion gap is one of the most powerful factors influencing seal life in a 3000 psi system and is even more important in an 8000 psi system. The range of 0.001 to 0.003 inch for diametrical clearances may be too large. The results seem to indicate that much longer life can be achieved if the extrusion gap is held to 0.002 or less.

(3) The cap strip must be relatively thick to provide acceptable wear at 8000 psi.

(4) TFE based seals leak more than rubber sealing elements. TFE seals may meet 25 cycles/drop requirement, but all really dry seals had rubber in contact with the rod.

(5) Bronze filled cap strips did not wear as well as some other materials. This may have been due to insufficient thickness of the cap seal but appears to also be attributable to the material.

(6) A two stage unvented seal can reverse pressurize the 1st stage seal; therefore, this should be considered in selecting the 1st stage configuration. Select a 1st stage with extrusion resistance in the reverse direction. A unidirectional seal for the 1st stage seal seems to add life to the second stage seal.

(7) The no-backup width cap strip is more stable than a one backup width cap strip.

(8) Glass/moly filled backups and cap strips did not cause rod scoring. Most of the test was long stroke which may have been a factor.

TABLE 4. Summary of Seal Test Results

Seal*	Test Hours Completed	Configuration	Remarks
Single Stage			
A	410.2	Bal Seal	Negligible wear
B	410.2	Double delta, 2 backups	Negligible wear, no nibbling of O-ring
C	410.2	Trapezoid	No nibbling of elastomer, minor wear on backup
D	253.1	Square seal, 2 backups	Failed. Backups worn, elastomer nibbled
L	39	Tee Seal	Failed. Elastomer nibbled badly
M	73.3	O-ring, 2 backups	No leakage. Installed at 294.9 hours. Backups extruded
Two Stage			
E	410.2	1. Bal Seal 2. O-ring, 2 backups	Negligible wear. Second stage experienced full load pressure throughout test
F	263.5	1. Double delta 2. Trapezoid	Failed. 1st stage failed from reverse pressurization. 2nd stage failed from wear-out of backup
G	410.2	1. Revocap 2. Tee seal	Revocap worn thru to O-ring. Tee seal had considerable wear
H	179.3	1. Revocap 2. Excluder	Failed. Cap strip wore out. Excluder then extruded
J	167.3	1. Tee Seal 2. Tee Seal	No leakage. Installed at 200.9 hours. Slight nibbling of 1st stage elastomer
K	142.1	1. Revocap 2. Trapezoid	No leakage. Installed at 268.1 hours. Cap strip worn thru

*See Figure 40 and Table 3.

(9) On excluders, the curling up of the scraping edge is a problem which limits effectiveness.

(10) Uncut filled backup rings can wear on the ID to a larger size and no longer be effective in eliminating nibbling if the backup material is not somewhat compliant. A hard backup ring such as nylon against the rubber is not compliant enough to keep the extrusion gap closed. In the "T" configuration, rapid nibbling occurred.

(11) Short duration testing of spiral backups indicated the thin member tends to extrude.

(12) With one exception, all elastomeric seals were made from MIL-P-83461 compound. No problems occurred with this compound.

(13) No problems occurred with the MIL-H-83282 test fluid.

Rod seal configurations recommended as candidates for LHS actuators were as follows:

Application	Recommended Rod Seal Configuration	Figure No.	Comments
Primary Flight Control Actuators	Two stage seal: -1st stage Cap seal with backup ring on each side -2nd stage O-ring with two backups on low pressure side	13	-Can be installed in standard unsplit groove -Provides dual seal redundancy -Rubber outer seal assures dryness
Automatic Flight Control System Actuators	Single stage seal: Cap seal with two backups on low pressure side	15	-Need to keep friction low
Utility Actuators	Single stage seal: Trapezoidal seal with trapezoidal backup	14	-Utility application has limited life requirement -Rubber outer seal assures dryness

5.1.5 Servo Valve Erosion Test

5.1.5.1 Test Procedure - The rod seal test was begun using a solenoid valve and limit switches to cycle the four test actuators. At 39.5 hours, a mechanical servo valve was installed to cycle the actuators. The servo valve provided smoother control and more flexibility in changing stroke lengths than the solenoid valve. It also provided an opportunity to evaluate servo valve erosion concurrently with the rod seal test and thereby minimize costs.

The servo valve assembly tested was Vought P/N 210-32263. This valve has a nominal orifice size of 0.060 in. length by 0.020 in. width. The valve was used throughout the remainder of the rod seal testing which was terminated at 410.2 hours. This provided 370.7 hours of servo valve operation at 8000 psi inlet pressure. The valve was stroked sinusoidally by an electrohydraulic actuator with position follow-up summed by a scissors linkage to null the valve. The peak flow rate was approximately 1.7 gpm during long stroke cycling of the test actuators.

The test fluid (MIL-H-83282) was filtered to 3 microns absolute by a filter in the pressure line between the pump and the servo valve. It is not known how strong a factor contaminant level is in influencing erosion. The current trend toward 5 micron absolute filtration should produce aircraft systems with a cleanliness level similar to that in the test set-up.

5.1.5.2 Test Results - The valve controller was examined under 10 power magnification for evidence of erosion on the metering lands and on the controller between lands. No sign of erosion was seen. The metering land corners were sharp. The top of the lands had a wear pattern which was apparently due to the reciprocating motion of the controller—not due to erosion. The test valve was a two system valve; however, only one side was active in the test. The land polishing was the same on the active half and the inactive half of the valve.

Three valve characteristics were measured before and after testing so that the amount of wear or degradation in performance could be determined. The measurements were made at 3000 psi since the laboratory where this work was done was not equipped for 8000 psi testing. The results are tabulated below:

Parameter	Before Test	After Test
Neutral leakage, gpm	0.075	0.095
Valve underlap, in. (average values)	0.00033	0.00051
Flow gain, gpm/in. (0.004 in. stroke)	42.5	46.25

Comparison of the before test and after test values indicates an average increase in underlap of 0.0002 in. per land during the test. Neutral leakage increased by 0.02 gpm. The short stroke flow gain increased slightly which is the expected result of increased underlap.

From the combination of visual inspection and post test performance, it was concluded that servo valve erosion should not be a problem in 8000 psi systems. This conclusion was based upon the test of a particular valve design wherein both the sleeve and the controller were made from 440C material with a Rockwell hardness in the range of C58 to C63. It should be recognized that valves made from softer materials or other design configurations could have a wear problem. However, the test valve was considered to be a state-of-the-art unit similar to most valves commonly in use, and contained no special features to enable it to operate at 8000 psi.

The test valve was underlapped. Valves being incorporated in lightweight hydraulic systems will be overlapped to minimize power loss (and heat generation). It is expected that this will have a beneficial effect on valve wear.

5.2 ACCEPTANCE TESTS

5.2.1 Major Components

Pump acceptance testing was conducted by NAAD. Two pumps were checked (FC-1 and FC-2). Performance checks run at the beginning of the compatibility endurance test (0 hours) were considered as the acceptance tests. The results were not completely satisfactory and are discussed in section 5.3.6.1. The tests conducted were:

- Overall efficiency
- Transient response
- Heat rejection

Actuator and reservoir acceptance testing was conducted by NAAD and Vought as shown on Table 5. The tests, as applicable, were:

- Proof pressure (12,000 psi)
- Functional
  - Operation
  - Internal/External Leakage

Control valve stop adjustments were made during actuator operation checks. All actuator and reservoir acceptance tests were completed satisfactorily.

Vought conducted extreme temperature and limited endurance cycling on the UHT, aileron, speed brake, and AFCS actuators. Test details and results are documented in Vought Report No. 2-59900/9R-52172. All results were considered satisfactory.

5.2.2 Minor Components

Component suppliers conducted proof pressure and various individual tests necessary to assure satisfactory operation, Table 6. All acceptance test results were satisfactory.

TABLE 5. Acceptance Tests, Major Components

Component	Tests Conducted	Tests Conducted By	Test Results	Test Results Reported In
LHS Pump	Efficiency Transient Response Heat Rejection	North American Aircraft Division	See section 5.3.6.1	NAAD Laboratory Record Book S/N N 1021
LHS Rudder Actuator	Proof Functional	North American Aircraft Division	Satisfactory	NAAD Laboratory Record Book S/N N 1021
LHS UHT Actuator	Proof Functional	Vought	Satisfactory	Vought Report 2-59900/9R-52172
LHS Aileron Actuator	Proof Functional	Vought	Satisfactory	Vought Report 2-59900/9R-52172
LHS Speed Brake Actuator	Proof Functional	Vought	Satisfactory	Vought Report 2-59900/9R-52172
LHS Reservoir (2)	Proof Functional	Vought	Satisfactory	Vought Report 206-LHS-6

TABLE 6. Acceptance Tests, Minor Components

LHS Component	Tests Conducted	Tests Conducted By	Test Results	Test Results Reported In
Accumulator	Proof @ +275°F Gas leakage Fluid leakage	Bendix Corporation Electrodynamics Div.	Satisfactory	Bendix Acceptance Test Report for P/N 3321471
Check Valve	Proof Internal/ External leakage	Gar-Kenyon Controls Div. MITE Corporation	Satisfactory	Gar-Kenyon document ATP 95200
Filter	Proof Bubble Point Differential Pressure Automatic Shut-off Degree of Filtration Collapse Pressure	Aircraft Porous Media, Inc. Pall Corporation	Satisfactory	APM document ATP-A640-83Y1
Hose	Proof	Titeflex Corporation	Satisfactory	Data not yet received LHS hose delivered 12-8-80
Pressure Gage	Proof Scale Error	QED/Inc.	Satisfactory	QED/Inc. document ATP 1218-63
Pressure Snubber	Proof *Restricted Flow*	Gar-Kenyon Controls Div. MITE Corporation	Satisfactory	Gar-Kenyon document ATP 95239
Pressure Transmitter	Proof Case Leakage Scale Error Pressure Switch	Courter, Inc. Bendix Corporation	Satisfactory	Courter P/N 18-243 Test Record per Q.C.T.P. 525-202 Rev. B
Quick Disconnect	Proof Leakage Vibration	Aeroquip Corporation	Satisfactory	Aeroquip Report No. 610011-4
Relief Valve	Proof Cracking Pressure Reseat Pressure	PneuDraulics, Inc.	Satisfactory	PneuDraulics document ATP 1257, ATP 1258
Restrictor	Proof Rated Flow	The Lee Company	Satisfactory	Lee document P.S. 280
4-Way Solenoid Valve	Proof Leakage	Bendix Corporation Electrodynamics Div.	Satisfactory	Bendix letter HYD-425-80
Tubing	Mechanical Properties Chemical Analysis Miscellaneous Inspections	Trent Tube	Satisfactory	Trent Tube document M.O. 1P5-20670-1

5.3 COMPATIBILITY TEST

5.3.1 Introduction

The compatibility test integrated six modules in the 8000 psi system to be assembled on the full scale simulator in Phase II. Primary purposes of this test were:

(1) Provide a means for powering the LHS actuators

(2) Permit preliminary evaluation of system pressure ripple and surge characteristics

(3) Provide a means for realistically endurance testing the LHS pumps, reservoirs, actuators, valves, etc.

Secondary purposes of the test include familiarization with the newly designed system and practical experience operating the system.

5.3.2 Test System

A floor layout of major sections in the system is given on Figure 44. Overall views of the laboratory setup are shown on Figures 45 and 46. The test modules were placed in locations approximating their future relative positions on the full scale simulator in Phase II. There were two independent 8000 psi hydraulic systems (FC-1 and FC-2), a 3000 psi system for loading four LHS actuators, and a 500 psi system for controlling the inputs of two LHS actuators, Figure 47. Tubing lengths used to connect LHS actuators with the power sections were based on lengths anticipated in the flight test aircraft, Figure 48. A schematic diagram of the 3000 psi load system is presented on Figure 49.

5.3.3 Instrumentation

The instrumentation system had three functions: controlling, monitoring, and recording. The principal sections were (1) control panel, (2) pressure gage panel, (3) temperature recorder, and (4) oscillograph recorder, Figure 50.

Controls

FC-1 and FC-2 pump on-off
FC-1 and FC-2 pump speed
FC-1 and FC-2 fluid temperature
FC-1 and FC-2 automatic shut-down
   resulting from fluid over-temp or fluid loss
Rudder, UHT, and aileron actuator cycling
   amplitude and frequency
Speed brake actuator cycling

Monitoring

FC-1 and FC-2 fluid temperatures
FC-1 and FC-2 pump inlet, outlet, and case pressures
FC-1 and FC-2 pump inlet and case flows
Load and control system pressures
Pump speed
Running time

Recording

FC-1 and FC-2 fluid temperatures
FC-1 and FC-2 pressures and flows
Pump speed

A block diagram of the instrumentation system is presented as Figure 51. Transducer locations, operating range, accuracies, and response capabilities are given in Table 7.

5.3.4 Test Procedure

5.3.4.1 Cycling - Compatibility test cycling was performed in three blocks of 50 hours duration (150 hours total cycling time). Each 50 hour block consisted of a cycling schedule designed to subject system components to realistic operating conditions. Actuator cycling was based on the load/stroke schedule given in MIL-C-5503. Twenty percent of the endurance test cycle requirements specified in MIL-C-5503 were run.

Automatic Flight Control Actuators

10,000 cycles		100% stroke and load
50,000 cycles		50% stroke and load
140,000 cycles		10% stroke and load
800,000 cycles		2% stroke and load
1,000,000 cycles	=	20% of 5,000,000 cycles specified in MIL-C-5503

Utility System Actuators

4,000 cycles		100% stroke and load
4,000 cycles	=	20% of 20,000 cycles specified in MIL-C-5503

The cycling sequence is detailed on Table 8. Each sequence step was one hour in duration. A summary of the cycles completed in a 50 hour block is given on Table 9. Actuator strokes and loads are listed on Table 10.

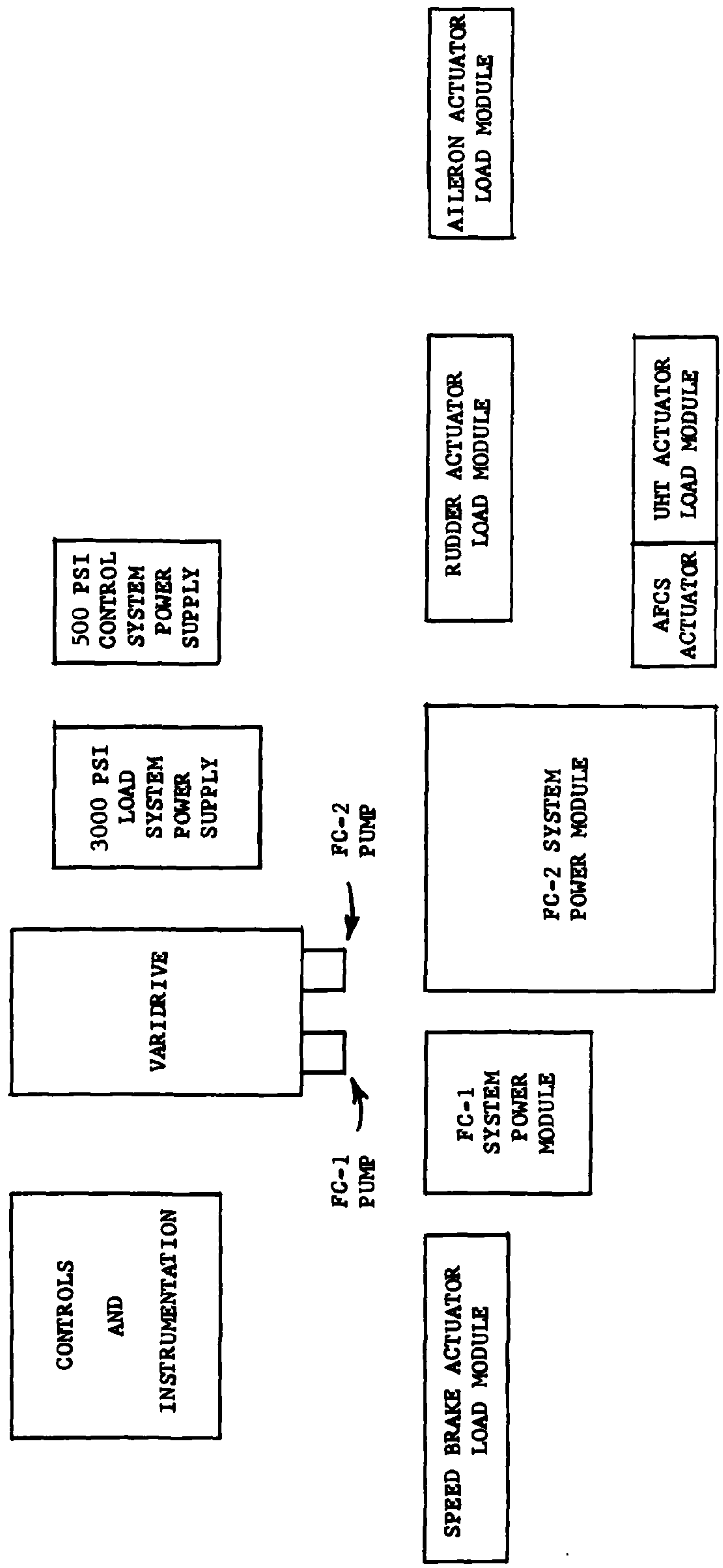


FIGURE 44. Floor layout of compatibility test system

FIGURE 45. Compatibility test setup (looking aft)

FIGURE 46. Compatibility test setup (looking forward)

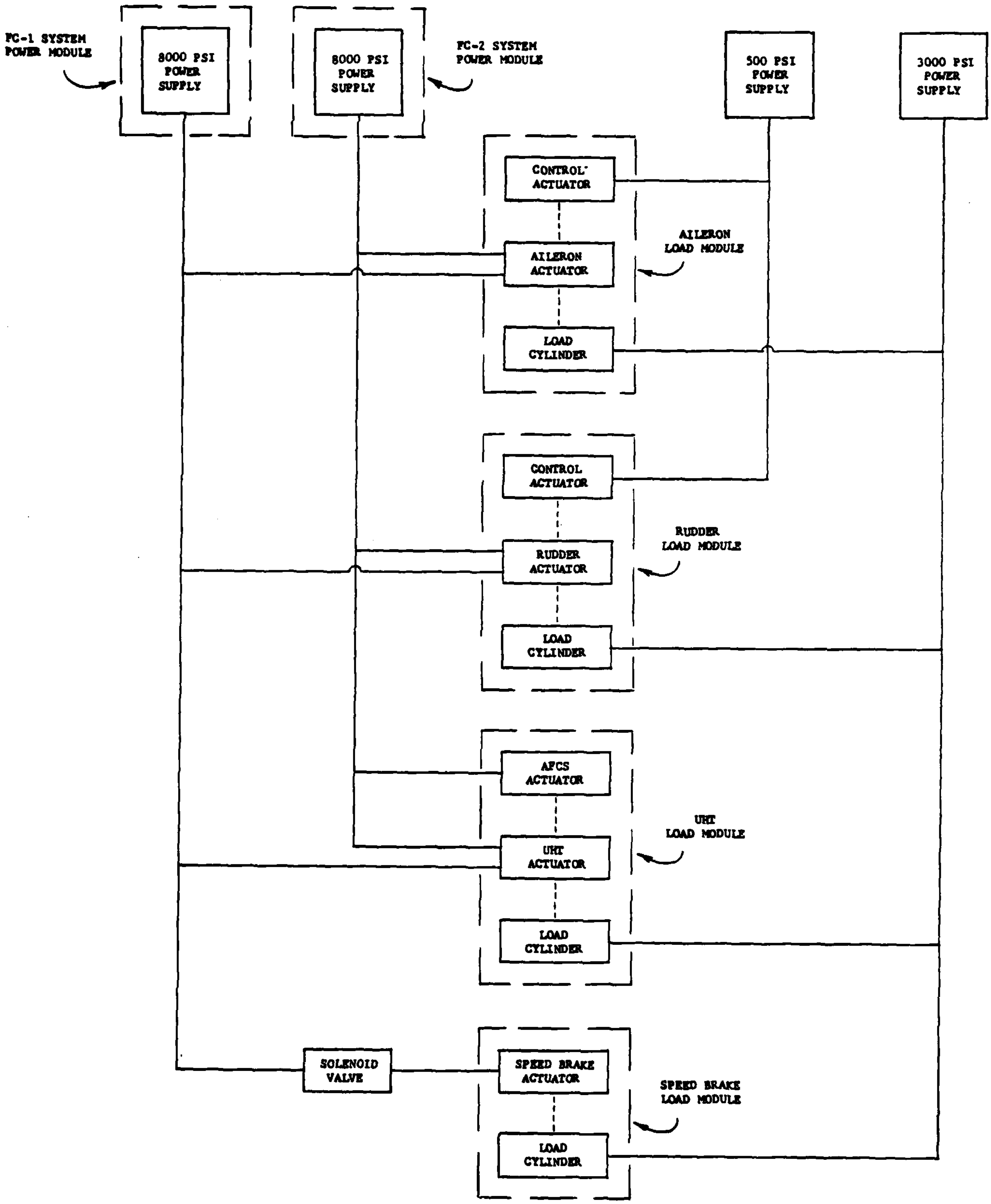


FIGURE 47. Compatibility test hydraulic systems

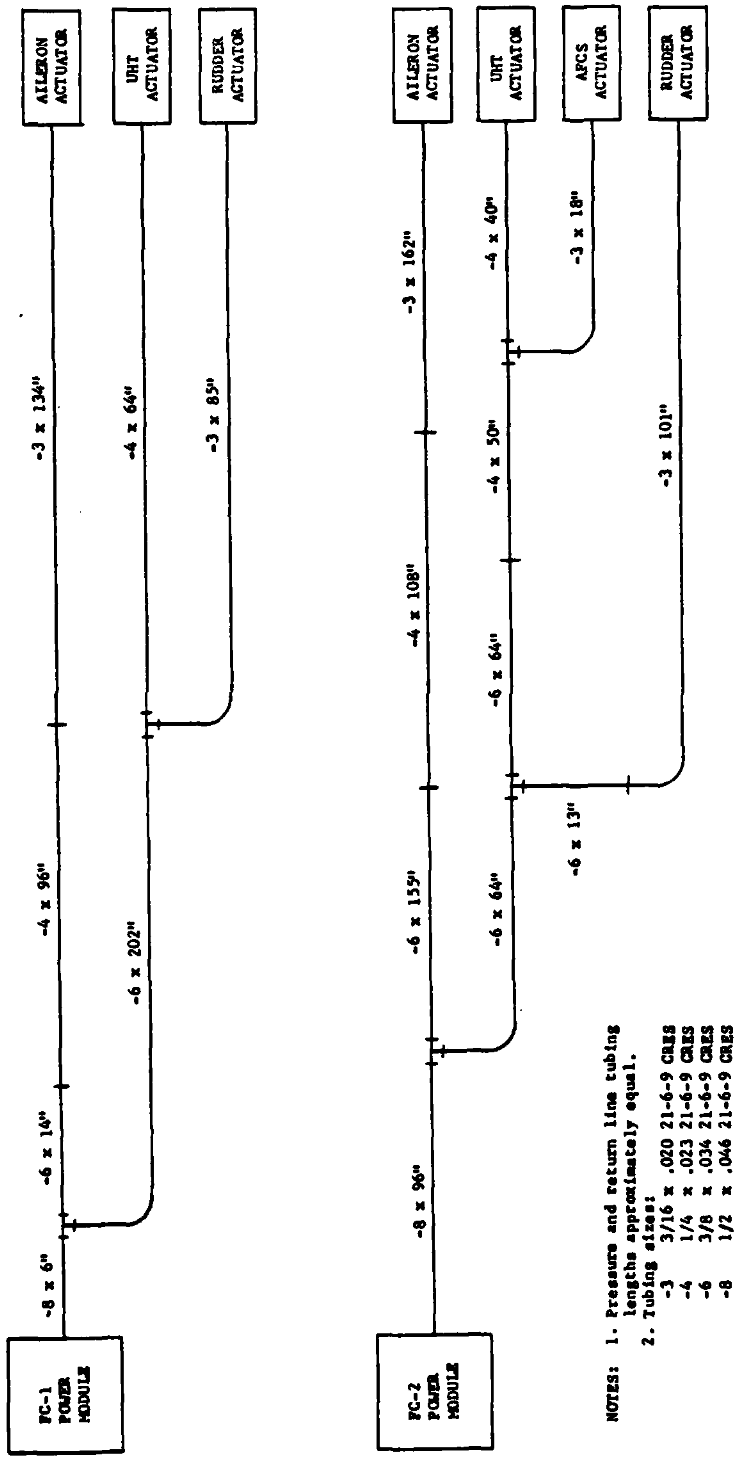


FIGURE 48. Power module-to-actuator tubing lengths

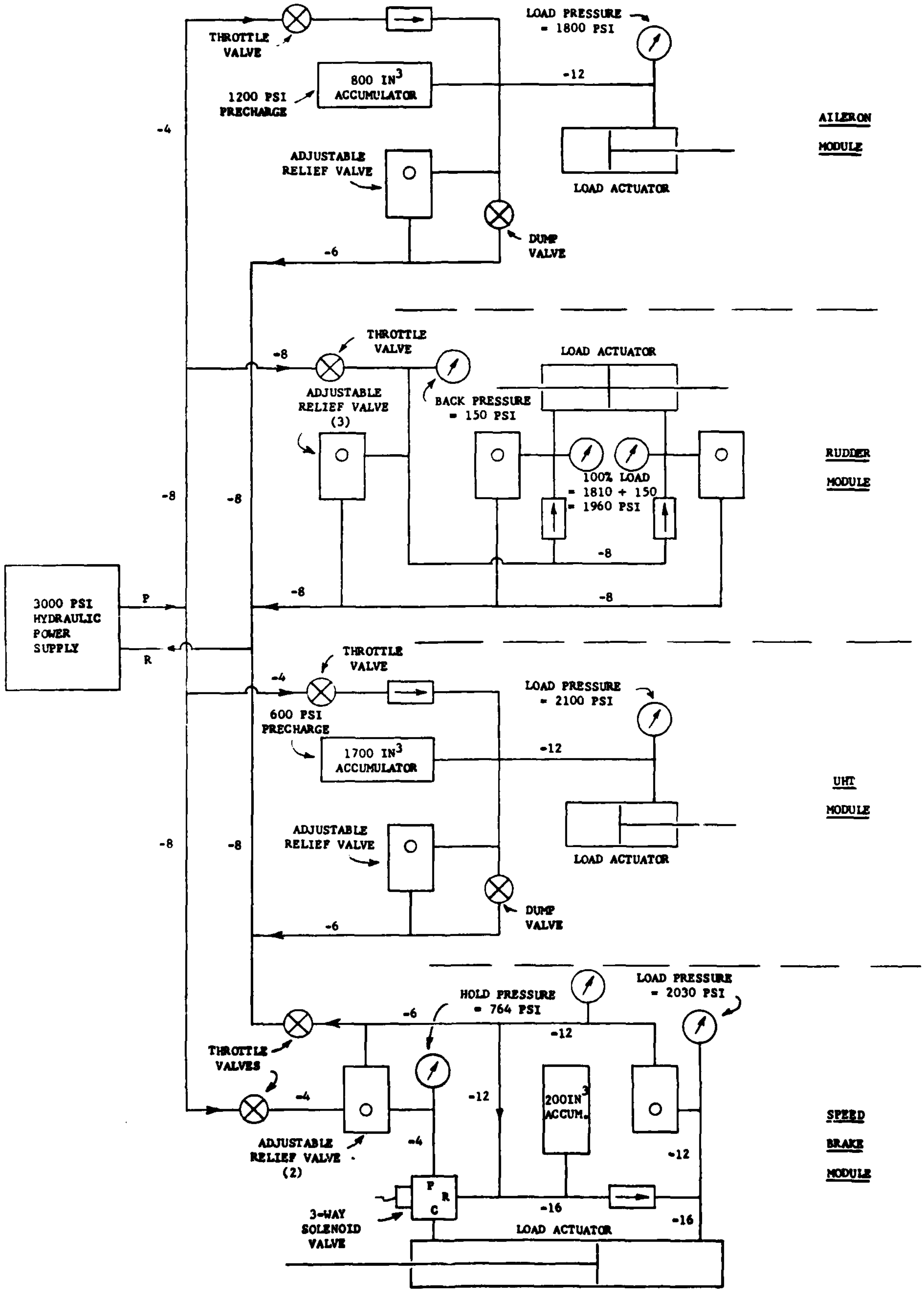


FIGURE 49. Hydraulic load system

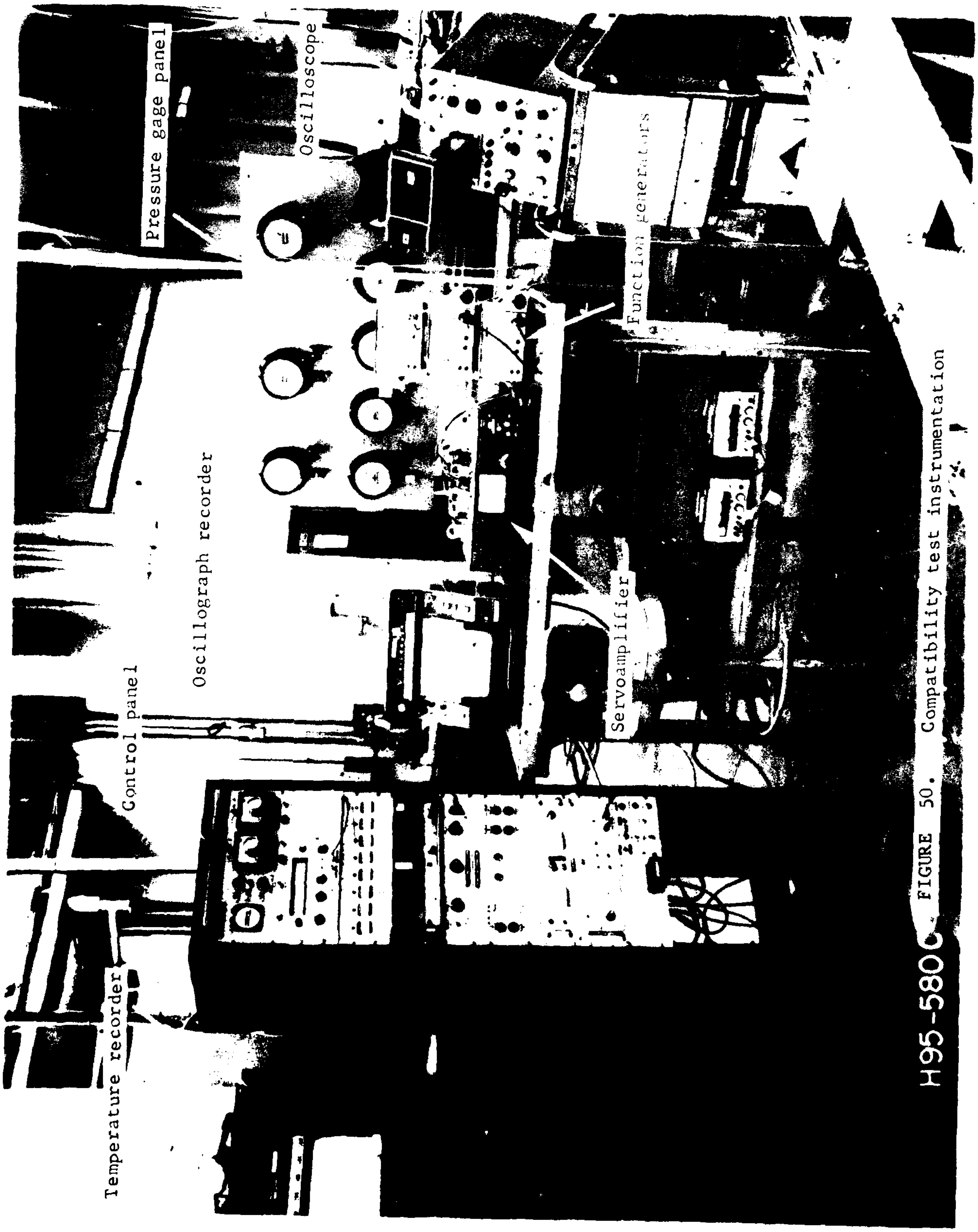


FIGURE 50. Compatibility test instrumentation

TABLE 7. List of Instrumentation

PARAMETER	SYSTEM	TRANSDUCER LOCATION	TRANSDUCER TYPE	RANGE	ACCURACY	READOUT RESPONSE
Temperatures						
T1	FC-1	Reservoir Outlet	Iron-Constantan thermocouple	-100 to +500°F	± 3°F	Sixteen temperature printouts every 35 seconds (16 channel recorder)
T2	FC-1	Pump Inlet				
T3	FC-1	Pump Outlet				
T4	FC-1	Pump Case Drain				
T5	FC-1	Heat Exchanger Outlet				
T6	FC-2	Reservoir Outlet				
T7	FC-2	Pump Inlet				
T8	FC-2	Pump Outlet				
T9	FC-2	Pump Case Drain				
T10	FC-2	Heat Exchanger Outlet				
T11	FC-2	Rudder Actuator Return				
T12	FC-1	UHT Actuator Return				
T13	FC-2	AFCS Actuator Return				
T14	FC-2	Aileron Actuator Return				
T15	FC-1	Speed Brake Actuator Return				
T16	--	Ambient				
Pressures						
P1	FC-1	Pump Inlet	Bonded strain gage bridge	0-500 psi	± 2%	600 Hz (response limited by oscillograph galvanometers)
P2	FC-1	Pump Outlet		0-10,000 psi		
P3	FC-1	Pump Case Drain		0-500 psi		
P4	FC-2	Pump Inlet		0-500 psi		
P5	FC-2	Pump Outlet		0-10,000 psi		
P6	FC-2	Pump Case Drain		0-500 psi		
P7	FC-2	Rudder Actuator Return		0-2000 psi		
P8	FC-1	UHT Actuator Return		0-2000 psi		
P9	FC-1	Pump Inlet	Dial pressure gage	0-200 psi	± 3%	Not applicable
P10	FC-1	Pump Outlet		0-10,000 psi		
P11	FC-1	Pump Case Drain		0-600 psi		
P12	FC-2	Pump Inlet		0-200 psi		
P13	FC-2	Pump Outlet		0-10,000 psi		
P14	FC-2	Pump Case Drain		0-600 psi		
P15	--	3000 psi System Discharge		0-5000 psi		
P16	--	500 psi System Discharge		0-2000 psi		
Flows						
F1	FC-1	Pump Inlet	Turbine flowmeter	0.4 - 10 gpm	± 1%	Not applicable (readout is frequency count)
F2	FC-1	Pump Case Drain		0.2 - 2.4 gpm		
F3	FC-2	Pump Inlet		0.4 - 10 gpm		
F4	FC-2	Pump Case Drain		0.2 - 2.4 gpm		
F5	FC-2	Rudder Actuator Return		0.4 - 5 gpm		
F6	FC-1	UHT Actuator Return		0.4 - 5 gpm		
F7	FC-2	Aileron Actuator Return		0.5 - 5 gpm		
F8	FC-1	Speed Brake Actuator Return		0.5 - 5 gpm		
Speed						
S1	FC-1 & FC-2	Pump Input Shaft	Magnetic, Tachometer	1700 - 8000 rpm	± 3% (est.)	Not applicable

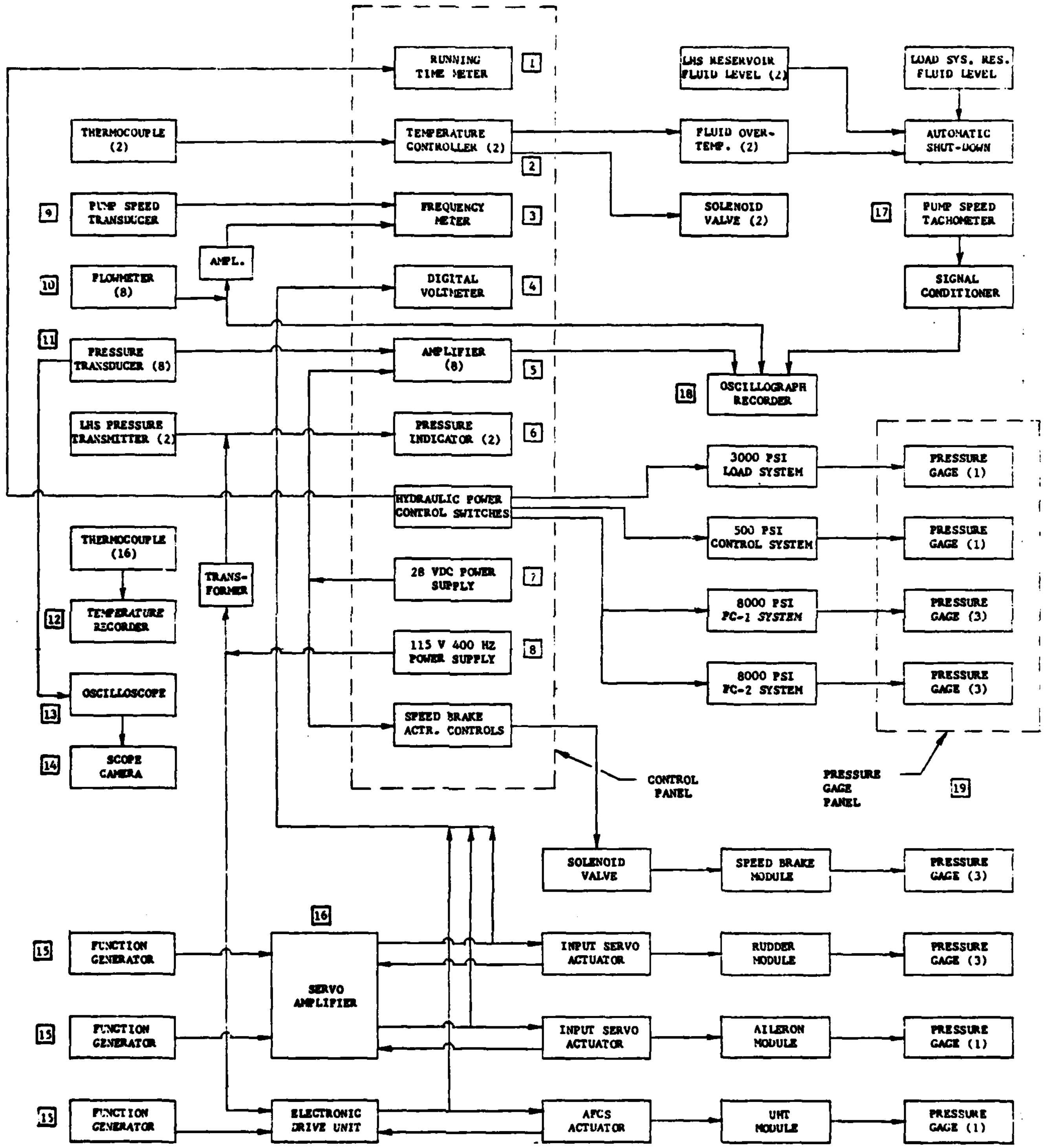


FIGURE 51. Instrumentation system

1	Running Time Meter, General Electric M/N 8KT 12DAB2
2	Temperature Controller, Love Controls M/N 56-848
3	Frequency Meter, Beckman M/N 6147
4	Digital Voltmeter, Dana M/N 5400
5	Amplifier, Viatran M/N 602
6	Pressure Indicator, MIL-I-25861, Vought P/N 218-21612
7	28 VDC Power Supply, Harrison Laboratories M/N 808A
8	115V 400 Hz Power Supply, Darcy/Behlman M/N 161A
9	Magnetic Pickup, Electro Products M/N 3010-AN
10	Turbine Flowmeter, Cox M/N 12SCRX, Waugh M/N FL-6S
11	Pressure Transducer, Viatran M/N 122EF76
12	Temperature Recorder, Brown Instruments M/N 153X(67)-P16H-II-III-(106)
13	Oscilloscope, Tektronix M/N 502A
14	Scope Camera, Hewlett Packard M/N 196A
15	Function Generator, Wavetek M/N 112
16	Servo Amplifier, Donner M/N 3500
17	Tachometer, Weston M/N 75B
18	Oscillograph, Minneapolis-Honeywell M/N 1108
19	Pressure Gages, Duragage, U.S. Gage, Ashcroft, Crosby

Figure 51. Instrumentation System (Continued)

TABLE 8. Actuator Cycling Sequences

Sequence Step No.	Load/ Stroke			Pump RPM	Pump Inlet Fluid Temp.
1-1	2%			3400	+180°F
-2	2%			5900	
-3	2%			5900	
-4	2%			5900	
-5	10%			5900	
-6	2%			3400	
-7	2%			3400	
-8	2%			3400	
2-1	2%			3400	+200°F
-2	10%			5900	
-3	10%			5900	
-4	10%			5900	
-5	10%			5900	
-6	10%			5900	
-7	2%			3400	
3,4,5-1	10%			3400	+200°F
-2	50%			5900	
-3	50%			5900	
-4	50%			5900	
-5	50%			5900	
-6	50%			5900	
-7	10%			3400	
	UHT	RUD	AIL		
6,7-1	2%	2%	2%	3400	+180°F
-2	100%	2%	2%	5900	
-3	100%	2%	2%	5900	
-4	2%	100%	2%	5900	
-5	2%	100%	2%	5900	
-6	2%	2%	100%	5900	
-7	2%	2%	100%	5900	

NOTE: 3400 RPM = Engine Idle
5900 RPM = Engine Military Rated Thrust

TABLE 9. Cycling Sequence Summary

Sequence Number	Duration, Hours/50 Hour Block Load/Stroke Magnitude 2%	10%	50%	100%		
1-	7	1				
2-	2	5				
3-		2	5			
4-		2	5			
5-		2	5			
6-	5			2		
7-	5			2		
TOTALS	19 +	12 +	15 +	4	=	50 hours
Cycling rate, cpm	186	56	15	11		
Total number of cycles in 50 hour block	212,000 +	40,300 +	13,500 +	2600	=	268,000 cycles/50 hr.
Total number of cycles in compatibility test	636,000 +	121,000 +	40,000 +	7800	=	800,000 NAAD cycles
					+	200,000 Vought cycles
						1,000,000 Total cycles completed

NOTES:

1. Load/stroke sequencing applies to UHT, rudder, and aileron actuators.

2. Speed brake actuator cycled at 100% load and stroke at 1 cpm during third 50 hour block.
   Total number of speed brake cycles: 3200 NAAD cycles
   800 Vought cycles
   4000 Total cycles completed

TABLE 10. Actuator Loads And Strokes

Load/Stroke Magnitude	Maximum Load, lb.			
	UHT	Rudder	Aileron	Speed Brake
2%	500 C (E) 500 T (R)	140 C&T	130 C&T	N/A
10%	1400 C (E) 2700 T (R)	690 C&T	660 C&T	N/A
50%	7,000 C (E) 13,400 T (R)	3450 C&T	3320 C&T	N/A
100%	13,900 C (E) 26,800 T (R)	6900 C&T	6650 C&T	40,000 C (E) 0 T (R)
	Total Stroke, in.			
2%	0.12	±0.03	±0.05	N/A
10%	0.56	±0.15	±0.25	N/A
50%	2.86	±0.74	±1.25	N/A
100%	5.72	±1.47	±2.50	19.94

NOTE:
C = Compression
T = Tension
E = Extending
R = Retracting
N/A = Not Applicable

5.3.4.2 Data

Laboratory notebooks were maintained to record and date all test activities including:

- Descriptions such as setup photographs, support equipment identification, test component part numbers, wiring diagrams

- Maintenance actions such as greasing bearings, tightening bolts, repairing test equipment

- Test actions such as making fluid patches, adding fluid to test system, fixing leaks, changing filter elements

- Test problems such as component malfunctions, failures, and removals

- Test results such as raw data and performance observations.

A test log sheet was used on which 13 parameters were recorded every 15 minutes of each sequence step: T2, T4, T7, T9, P10, P13, P14, F1, F2, F3, F4, and S1 (reference Table 7). Pertinent test actions were also recorded on the log sheet. Date, time of day, sequence step, and cycling time were an integral part of the record.

5.3.4.3 Startup - A detail startup plan was prepared to insure that test components were not accidentally damaged due to improper rigging, faulty hydraulic connections, fluid contamination, or incorrect operating procedure.

Actuator Rigging - The rudder and aileron input control actuators were operated and adjusted so that stroke lengths coincided with the test actuator stroke requirements. The AFCS actuator was operated, using a small portable hydraulic power supply, to check out the torque motor and electronic drive unit (reference paragraph 3.1.2). Control linkage between the AFCS and UHT actuators was then adjusted so that the electrical and mechanical nulls of the AFCS actuator coincided with the output null position of the UHT actuator. No rigging was required for the speed brake actuator.

System Fill - FC-1 and FC-2 were pressure filled with MIL-H-83282 fluid through the fill fittings and bled at numerous locations in both systems. The volume of fluid put in each system was recorded. A 3000 psi laboratory pump was installed in each system (in place of the 8000 psi test pumps). The 3000 psi pumps were run at low speeds and pressures and the two systems were checked for leaks. All test actuators were slowly cycled full stroke. Pressure was then increased to 3000 psi and the systems checked for satisfactory operation.

Proof Test - All components--filters, check valves, relief valves, quick disconnects, pressure transmitters, actuators, etc.--were removed; only tubing and fittings were proofed. Where necessary, temporary tube assemblies were installed to replace missing components. Each system (FC-1 and FC-2) was proof tested individually; all plumbing in each system was proofed simultaneously. A hand pump was used to apply pressure. For safety, an extension tube was employed to permit the hand pump to be located in an adjacent room. The proof test consisted of applying 16,000 psi for 2 minutes, releasing the pressure, and re-applying 16,000 psi for 2 minutes.

Fluid Cleanup - FC-1 and FC-2 systems were operated at 3000 psi, using the laboratory pumps, with the test actuators cycling full stroke slowly. The systems were run continuously for two hours after which fluid samples were taken for contamination checks. Fluid cleanup was completed when the contamination level was Class 8 (NAS 1638) or better.

System Stability - The system was operated at a low pressure level using the 8000 psi test pumps. This was done by opening a needle valve installed in each power module. With all actuators at null or off and the pumps running at 1800 rpm, the pressure in FC-1 was slowly increased to 8000 psi by closing the needle valve; the needle valve in FC-2 was then closed slowly. When it was clear that FC-1 and FC-2 were operating satisfactorily, pump speed was slowly increased to 5900 rpm in a preliminary search for hydraulic resonance and instabilities based on audible observations.

Temperature Control - FC-1 and FC-2 modules each had an oil-to-water heat exchanger, water solenoid valve, and autommatic electrical controls to maintain desired fluid temperature levels. The operation of this equipment was checked by setting the controllers for +180°F, running FC-1 and FC-2 at 8000 psi, and observing system temperatures on the temperature recorder.

5.3.4.4 Performance Checks - Component performance checks were made at 0, 50, 100, and 150 hours.

Pump - Pump testing was conducted on a setup with instrumentation which provided the following data: (See Reference 5 for setup details.)

Steady-State Tests:

Pump speed
Input torque
Pressure: inlet, discharge, case
Fluid Temp.: inlet, discharge, case
Flow: case, discharge (measured at return pressure)

Dynamic Tests:

Pressure: peak, ripple
Transient response time

Overall efficiency and heat rejection were determined for the following operating conditions:

Pump speed:	5900 rpm
Inlet fluid temp.:	+200°F
Inlet pressure:	70 psig
Case pressure:	120 psig

The transient tests were run using a fast operating solenoid valve to cycle discharge flow from 5% to 90% to 5% of maximum flow. Pressure transients and pump ripple were observed on an oscilloscope and recorded photographically. Pressure system volume was approximately 125 in^3.

Actuators - Aileron, rudder, and UHT actuator control valve null leakage and piston rod seal leakage were determined. Null leakage was measured at room temperature with 8000 psi applied. Leakage was collected in a graduate from open return ports (FC-1 and FC-2). Rod seal leakage was caught during endurance cycling in a small container placed under each actuator. The accumulated leakage was then measured in drops using an eye dropper.

Filters - Patch tests were run on the pressure, return, and pump case drain filters in each system (FC-1 and FC-2). The procedure consisted of: 1) flushing the outer surface of a filter element with petroleum solvent and passing the effluent through an 0.5 micron filter patch; and 2) passing the MIL-H-83282 fluid and debris in the filter bowl through the same filter patch. Each of the six patches were then examined for types and concentration of particles collected.

Fluid - Hydraulic fluid was taken from a sampling valve located in the return section of each power module. A sample consisted of approximately 200 cc of fluid collected in a specially cleaned sample jar. Care was exercised to minimize introduction of foreign contaminants when the sample was taken. The sealed jars were then allowed to set for a minimum of 24 hours to allow dissolved air to escape. Particulate contamination was then determined using a Hiac automatic particle counter M/N PC204. Fluid from each contamination check was saved and used for determination of kinematic viscosity. This was done at +100°F using a standard viscometer.

Relief Valve - Relief valve cracking pressure, reseat pressure, and internal leakage were determined. The valve was installed in a setup powered by Abex pump M/N AP6V-57. This pump has a pressure compensator with an adjustment range up to 9200 psi. A flowmeter was placed in the relief valve return line. With the pump compensator adjusted to its maximum setting and the pump operating, pressure on the relief valve was slowly increased above 8000 psi by closing a system needle valve. Cracking pressure was recorded when flow was sensed by the flowmeter. Pressure was increased until the relief valve was full open, then decreased until return flow was zero and reseat pressure was recorded. This procedure was repeated several

times to obtain average values for cracking and reseat pressure. Internal leakage was determined at room temperature with 8000 psi on the valve and the return port open. Leakage was measured after waiting 3 minutes for the rate to stabilize.

Restrictor - Flow was determined with a differential pressure of 7800 psi applied across the restrictor. Flow at return pressure was measured for both flow directions. Compressed flow at 7800 psi was calculated using inlet and outlet fluid temperatures and pressures and fluid density curves, Reference 17.

5.3.5 Test Notes

The compatibility test was originally scheduled to begin in March 1980 following completion of the LHS component endurance and pressure impulse tests. Delivery of several important LHS components were delayed because of development and manufacturing problems. These delays affected the LHS test schedule and test procedures. The following sections present information relative to these delays and the changes in test procedure necessitated by the delays. Compatibility test cycling was begun 27 August 1980 and completed 10 November 1980. Pressure impulse and component endurance testing was begun 26 November 1980 and completed 16 January 1981.

5.3.5.1 LHS Pump - Minor difficulties usually accompany the first-time fabrication of any new pump design. Tolerances, materials processing, quality control, etc., can cause problems; design modifications often cause delays. Development of the LHS pump was typical of conventional designs; the units functioned well, but there were several performance areas which could be improved with design changes. To avoid undue delays in the LHS program schedule, the compatibility test was begun using "interim pumps". These units had higher than desired heat rejection and excessive pressure droop. The LHS pumps to be used on the ground simulator in Phase II are expected to meet all performance requirements.

The compatibility test was stopped 3 times because of "interim pump" problems. In order to avoid further delays in the LHS program, a decision was made at the 102.7 hour point to complete the compatibility test using two backup pumps. These units, built by Abex Corporation, were evaluated in the LHS Exploratory Development Program reported in References 1 through 7. The Abex pump is shown on Figure 23.

5.3.5.2 LHS Actuator - The AFCS actuator has two parallel cylinders with pistons moving in opposite directions. Each piston has an LVDT feedback pot. Since there was only one control valve, reference section 3.1.2, only one feedback loop could be used. In order to provide smooth operation, #2 cylinder in the AFCS actuator was employed to drive the UHT actuator input linkage; #1 cylinder was pressurized but was not cycled during the compatibility test.

5.3.5.3 LHS Hose - Fabrication of the LHS hose was delayed because of manufacturing problems. Titeflex Corporation therefore provided "interim hoses" for use at the pumps in the compatibility test. These units were satisfactory strength-wise but were heavier than the anticipated weight of the LHS hose. The LHS hoses, -8 size x 30 in. long, were delivered in December 1980.

5.3.5.4 LHS 4-Way Solenoid Valve - This valve is used to control the speed brake actuator. Delivery was delayed because of manufacturing problems, and the compatibility test was begun without it. The required 3200 speed brake cycles were to be run later using an accelerated cycling schedule. The valve was received 20 October 1980, and installed on FC-1 power module just prior to the start of the third 50 hour test block. The valve operated the speed brake satisfactorily for 1049 cycles at which time it ceased to function. The unit was returned to the supplier for failure analysis. To avoid further delays and to complete the cycling requirements of the speed brake actuator, two 3-way valves were installed on FC-1 power module to replace the 4-way valve. The 3-way valves, manufactured by Sterer Engineering and Manufacturing Company, were evaluated in the LHS Exploratory Development Program reported in References 1 through 7.

5.3.5.5 LHS Fittings - Permanent type fittings used were manufactured by Deutsch and Raychem; separable fittings were Dynatube (Resistoflex) and Permaswage (Deutsch). Tooling is required to swage the Dynatube and Deutsch fittings onto tubing. Fitting sizes to be swaged were -3 (3/16 in. tube O.D.) and -8 (1/2 in. tube O.D.). No -4, -5, or -6 size tubing are used in the pressure systems on FC-1 and FC-2 power modules. All -4 and -6 size tubing used to connect the power modules with the load modules were fabricated with MS flareless type fittings. No -5 size tubing was procured.

Tooling for -3 size Dynatube fittings was not available when the compatibility test setup was fabricated because of development problems. To avoid delays, Raychem shrink-fit couplings (P/N 3P00101-3) were used to attach specially machined Dynatube fittings (P/N R44296T-03) to the -3 size tubing. This approach permitted evaluation of an excellent alternative should -3 size Dynatube tooling prove to be impractical. Tooling for -3 size Dynatube fittings was delivered 30 September 1980. Evaluation of this tooling will be made in Phase II.

The rudder module has -3 size plumbing. Since the rudder actuator was tested before the -3 tooling problem was resolved, a different style -3 Dynatube fitting was employed--butt-welded fittings used in the LHS Exploratory Development Program, Reference 6. Four of these fittings were employed on the rudder module.

5.3.5.6 LHS Fluid - The shear stability of MIL-H-83282 was planned to be evaluated during the compatibility test. As testing progressed, it became apparent the evaluation would not be completely valid because of the quantities of fluid which were periodically removed from FC-1 and FC-2 for filter patches, fluid contamination checks, component removals, etc.

Description	Total Fluid Removed During Compatibility Test, cc
Filter patch tests	2600
Fluid contamination/ viscosity samples	3200
Pump changes	2000
FC-2 weekend leak	1800
Component installations/ removals	10,000+

System fluid levels were replenished with new MIL-H-83282. Since both systems were periodically diluted with new fluid to maintain proper reservoir fill levels, fluid circulation cycles were reduced significantly from what would have occurred if the original fluid volume could have been maintained.

5.3.6 Test Results

5.3.6.1 LHS Pump - Interim pump performance at the beginning of the compatibility test is shown on Figure 52. Discharge flow was satisfactory except that flow cut-off was too gradual (excessive pressure droop). Flow cut-off from 10 gpm to 0.5 gpm is required to occur between 7700 and 8000 psi discharge pressure (300 psi droop). FC-1 pump droop was 700 psi; FC-2 was 550 psi. Revised pump timing and increased yoke moment should reduce the droop.

Maximum heat rejection of FC-1 pump was 390 BTU/min.; FC-2 pump had 615 BTU/min. The design goal was 300 BTU/min. maximum. Principal causes of the high heat rejection were distortion in the aluminum valve block and excessive piston-to-bore clearance. These are both correctable conditions.

Maximum overall efficiency of FC-1 and FC-2 pumps was approximately 85% and 80%, respectively. The design goal was 85% minimum. Improved heat rejection should increase overall efficiency to more acceptable levels.

Pump ripple and transient response are shown on Figure 53; both were satisfactory. FC-1 pump ripple was $\pm$160 psi; FC-2 was $\pm$204 psi. The design goal was $\pm$200 psi maximum. Transient response times were:

Pump	Condition	Observed Time, sec.		Max. Allowable Time, sec.
FC-1	90% to 5% flow	T_1	0.022	0.050
	5% to 90% flow	T_2	0.030	0.050
	Stability	T_S	0.207	1.00
FC-2	90% to 5% flow	T_1	0.020	0.050
	5% to 90% flow	T_2	0.027	0.050
	Stability	T_S	0.237	1.00

Pump performance data at 50 hours are listed on Table 11; data at 0 hours are shown for comparison. During transient response testing at 50 hours, FC-1 pump case flow suddenly increased to more than 3 gpm. The pump was returned to Sperry-Vickers for disassembly and examination. Part of one piston shoe was found to be missing. The cause was determined to be brazing voids—a quality control problem. (The possibility existed that this condition was also present to some degree in FC-2 pump.) Wear on parts in the FC-1 unit was observed during the tear-down. Maximum wear normally occurs on the porting plate interface, piston/bore interfaces, and piston shoes. No unusual wear was observed in any of these areas.

FC-1 pump was repaired and returned to NAAD-Columbus, and the second 50 hour block of hours was begun. A pin hole leak developed in the aluminum valve block of FC-1 pump at 56.2 hours, and the unit was again returned to Sperry-Vickers for disassembly and repair. Steel valve blocks were planned to be used on the LHS pumps but were not yet available for installation, so the "interim pump" was reassembled using an aluminum valve block from a development pump.

Pump performance data were not taken at the 100 hour check point since pump modifications were planned. At 102.7 hours, FC-2 pump developed an external leak in the control pressure porting section of the aluminum valve block. Erosion pitting occurred in a static seal gland bore surface, causing the seal to fail. FC-1 and FC-2 pumps were both returned to the supplier for examination and modification. The 150 hour compatibility test was completed using two backup pumps, Abex M/N AP6V-57, developed for the LHS Exploratory Development Program, Reference 2. No performance data was taken on the Abex units.

5.3.6.2 LHS Actuators - Actuator control valve null leakage and rod seal leakage are given on Table 12. Null leakage of all actuators was less than the maximum allowable 120 cc/min. (0.15 hp loss). Rod seal leakage of all actuators was less than the maximum allowable 1 drop/25 cycles (MIL-C-5503 requirement).

A significant quantity of black colored wear debris accumulated on the UHT actuator piston rod and at the mid-actuator vent hole during the course of the 150 hour test. The debris was believed to be the result of wear on the second stage backup rings; no excessive leakage was observed at any time. No unusual quantities of wear debris were observed on the rudder or aileron piston rods. The source of the black wear debris will be determined when the UHT actuator is disassembled.

The rudder actuator did not perform satisfactorily when first received for acceptance testing. The control valve tended to stick when allowed to remain at one position for a short time; null leakage was nearly zero with 8000 psi applied. The sticking was eliminated by honing the inside diameter of the control valve sleeve. The UHT actuator control valve also tended to stick, but not as severely as the rudder valve. The UHT control valve was not reworked prior to the compatibility test. Valve sticking generally occurred during startups and null leakage measurements, but was not a problem during test cycling. Sticking was not observed in the aileron control valve.

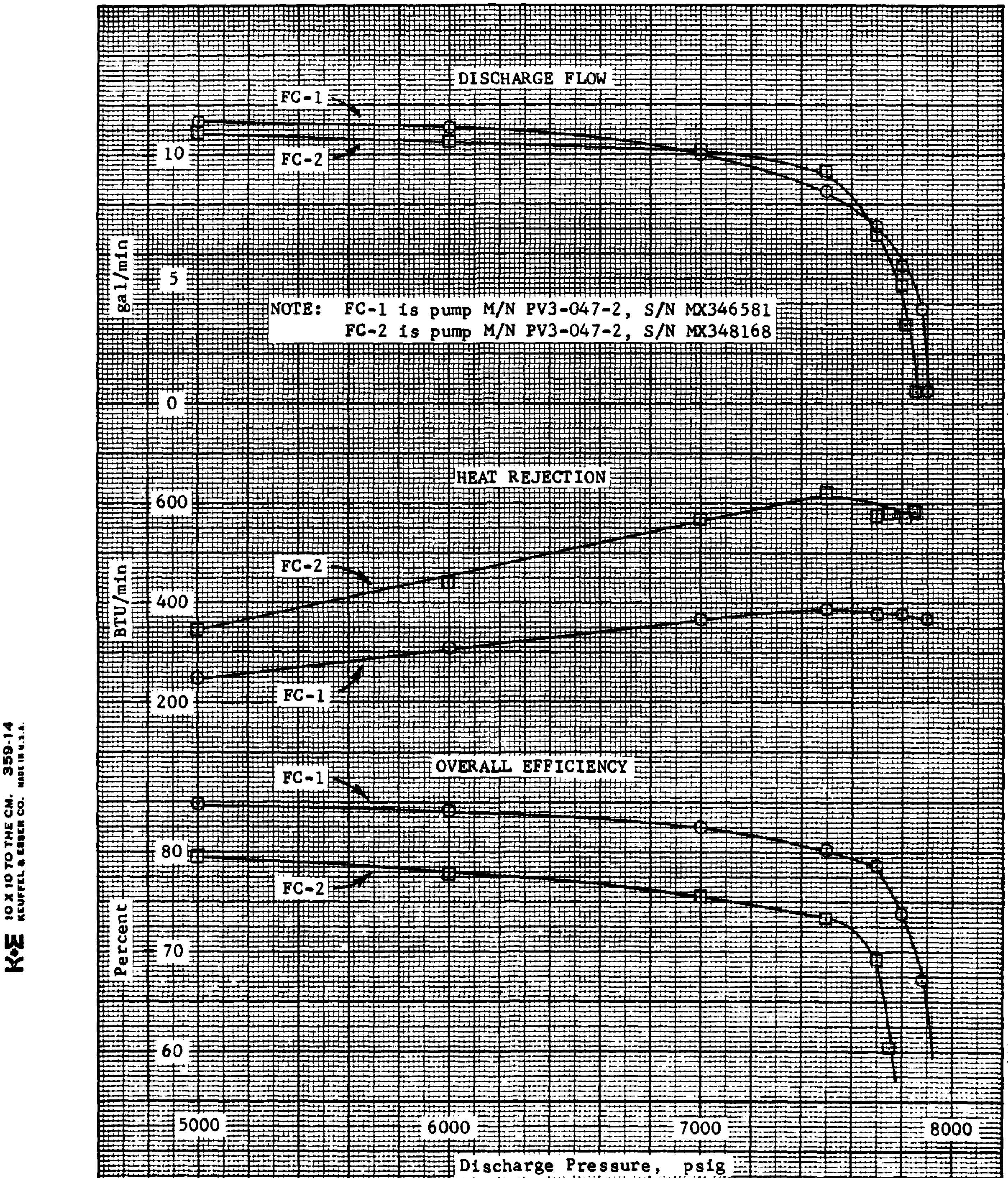


FIGURE 52. Interim pump performance curves

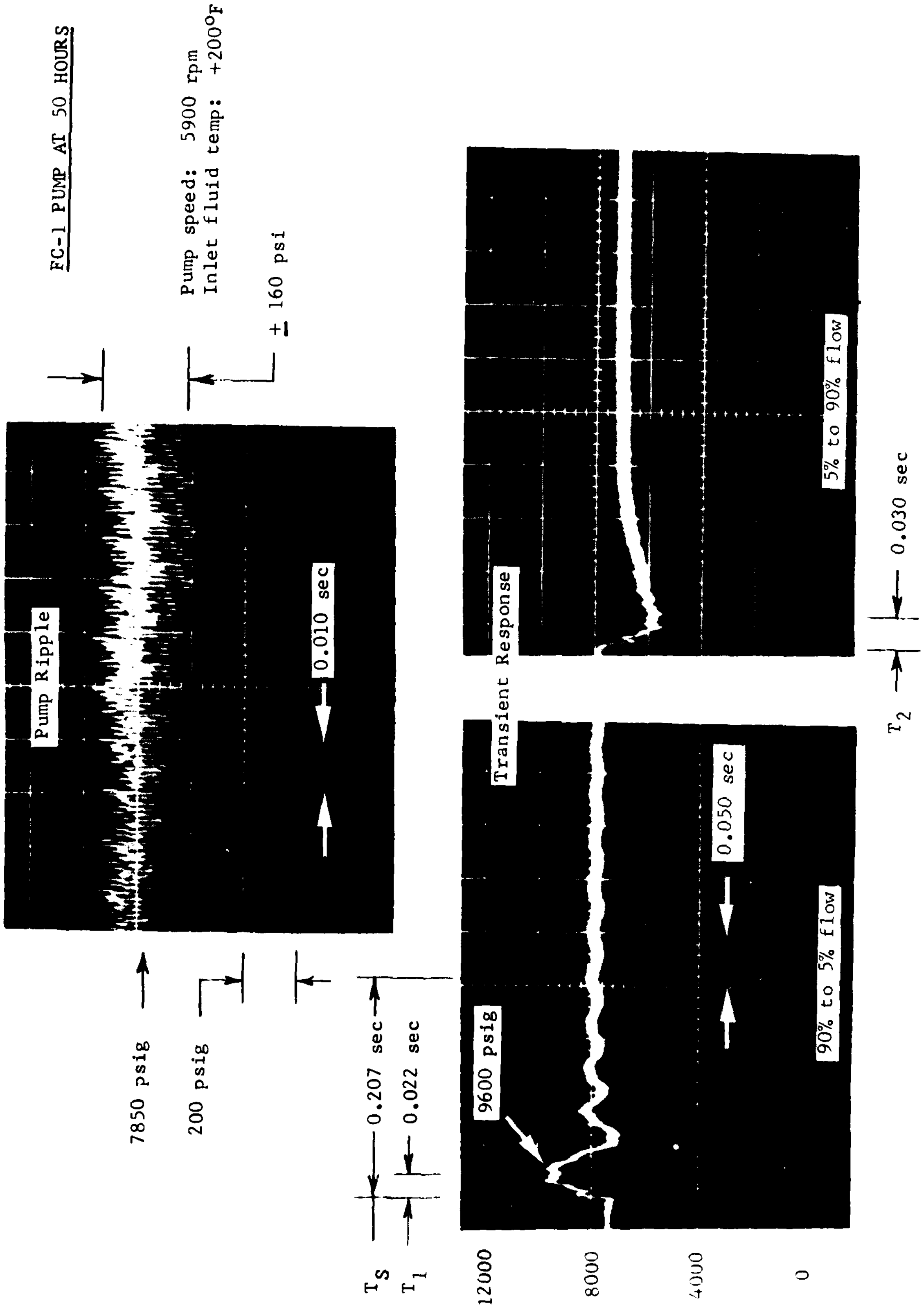


FIGURE 53. Interim pump ripple and transient response

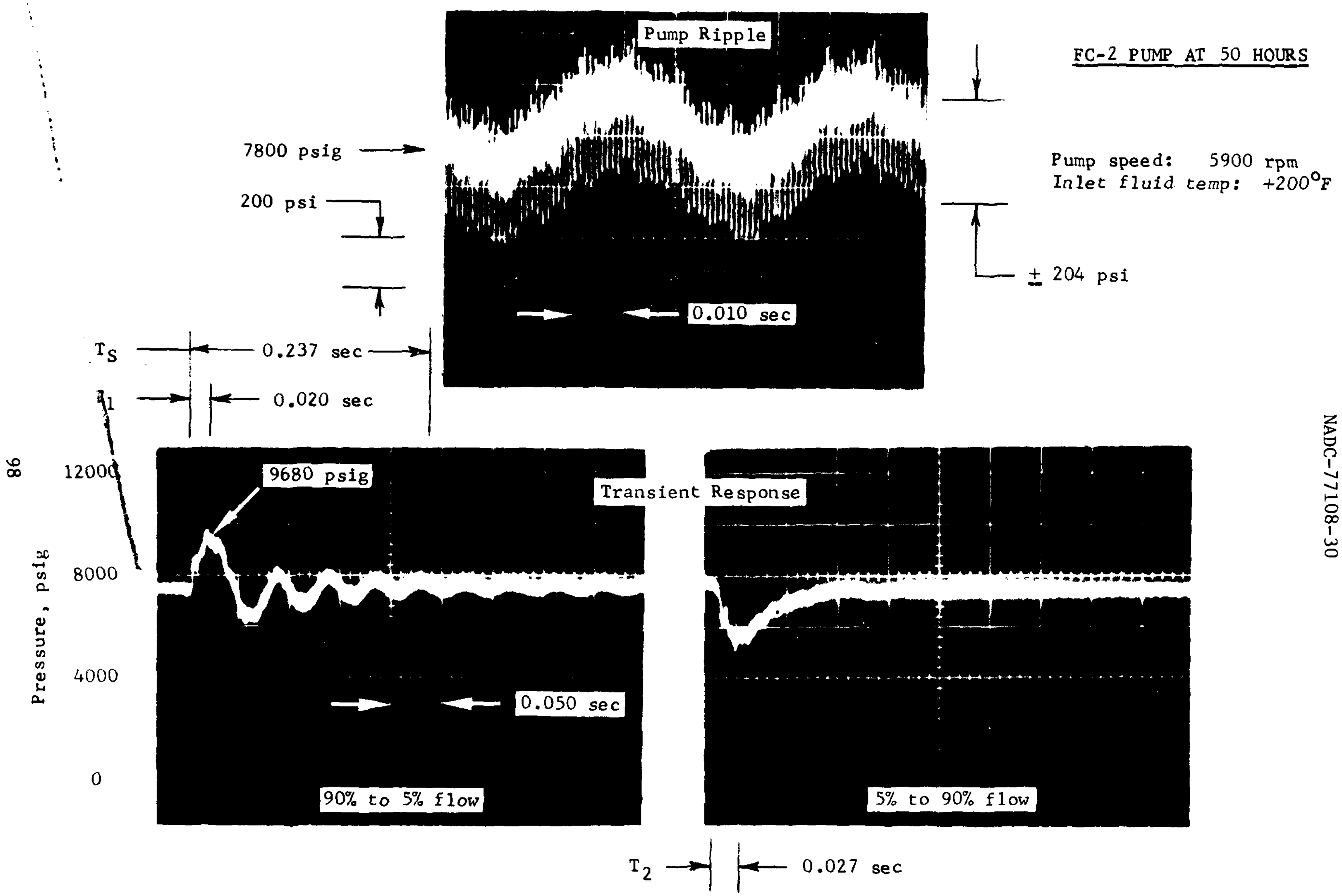


FIGURE 53. (Continued)

TABLE 11. Pump Performance Comparisons

Pump	Pump Speed, RPM	Inlet Press., PSIG	Case Press., PSIG	Inlet Temp., °F	Disch. Press., PSI	Case Drain Temp., O°F		Case Drain Flow, GPM		Disch. Flow, GPM		Input Torque, Lb-In		Heat Rej. BTU/Min.		Overall Efficiency, %	
						0 Hr.	50 Hr.	0 Hr.	50 Hr.	0 Hr.	50 Hr.	0 Hr.	50 Hr.	0 Hr.	50 Hr.	0 Hr.	50 Hr.
FC-1	5900	70	120	+200	4000	248	248	.06	.77	11.59	11.13	339	335	199	248	85.2	81.3
S/N 346581					5000	250	247	.21	1.08	11.37	10.71	417	409	249	318	84.9	80.4
					6000	254	251	.36	1.39	11.11	10.14	493	486	309	442	84.2	77.1
					7000	258	255	.51	1.64	9.99	9.32	528	536	367	531	82.5	75.1
					7500	260	258	.64	1.82	8.51	8.79	495	553	387	580	80.3	73.6
					7700	259	259	.72	1.86	7.21	8.54	440	562	374	619	78.6	72.2
					7800	259	259	.78	1.94	5.49	7.90	362	537	378	622	73.7	70.8
					7850		260		1.99		7.33		511		619		69.5
					7880	259		.80		3.80		278		363		67.1	
					7900	273	260	.89	2.06	.46	6.46	115	470	367	614	19.7	67.1
					7950		261		2.20		.47		165		563		14.0
FC-2	5900	70	120	+200	4000	243	243	.37	.69	11.34	10.98	348	344	279	298	79.8	78.2
S/N 348168					5000	253	251	.56	.90	10.90	10.61	421	419	343	370	79.5	77.8
					6000	260	254	.78	1.15	10.53	10.24	500	497	440	471	77.8	76.1
					7000	264	257	1.02	1.45	10.18	9.82	582	576	566	604	75.5	73.6
					7500	268	260	1.17	1.61	9.29	9.37	587	602	623	668	73.2	72.0
					7700	268	265	1.38	1.83	6.76	6.10	465	450	571	636	69.1	64.4
					7750	271	265	1.50	1.93	4.70	4.30	373	370	588	652	60.3	55.6
					7800		267		2.04		2.02		258		638		37.7
					7810	273		1.60		3.16		296		570		51.5	
					7820		271		2.16		.47		177		613		12.8
					7850	277		1.75		.41		167		584		11.9	

Table 12. Actuator Performance Summary

*Control Valve Null Leakage, cc/min.

Test Hours	UHT FC-1	UHT FC-2	Rudder FC-1	Rudder FC-2	Aileron FC-1	Aileron FC-2
0	16	30	21.5	35.5	4.6	9.2
50	4.1	17	15.5	33	4.9	47
100	8.5	17.2	9.6	32	2.5	19
150	9.2	10.8	3.8	25.2	11.0	53

**Rod Seal Leakage, cycles/drop

Test Hours	UHT	Rudder	Aileron
0	-	-	-
50	786	17,867	2602
100	1418	6700	3229
150	2414	44,667	2436

*Leakage measured at room temperature with 8000 psi applied pressure. Maximum allowable leakage = 120 cc/min.

**Leakage collected in small container under actuator and measured with eye dropper. Maximum allowable leakage = one drop/25 cycles.

The AFCS actuator developed rough operation at 128 hours (676,200 cycles). Since only cylinder #2 was being used, it was disconnected and cylinder #1 was plumbed to the control valve (see section 5.3.5.2). This permitted UHT actuator cycling to continue without serious delay. The cause of the rough operation will be determined when the AFCS actuator is disassembled.

5.3.6.3 LHS Filters - Six filters were evaluated:

FC-1 and FC-2	System Pressure (LHS filters)
FC-1 and FC-2	System Return (Std. A/C design)
FC-1 and FC-2	Pump Case Drain (A-7E filters)

All elements had 5 micron absolute filtration ratings. The system pressure and pump case drain housings had ΔP buttons to indicate filter element condition. As shown on Table 13, the filters maintained system cleanliness at a Class 8 (NAS 1638) level or better. Relatively few circulating particles were larger than 15 microns in size. Filter patches taken at the 150 hour point are shown on Figure 54. These are typical of other patches taken periodically throughout the test. Large quantities of extremely small black particles were present on all patches. In addition, the pressure filter patches usually had a small number of tiny metallic particles; the return filter patches had normal quantities of seal wear debris and miscellaneous metallic particles; and the case drain filter patches had typical pump wear particles.

The small black particles loaded the pump case drain filter elements such that it was necessary to change these elements four times during the test as shown on Table 14. The pressure and return filter elements had a larger contaminant holding capacity than the case drain filters and were not changed. The black particles are discussed in section 5.3.6.5.

5.3.6.4 LHS Fittings

Proof Test - A swaged joint on a permanent tee, Deutsch P/N DNR 10023-080308, failed at 15,500 psi during the proof pressure test on FC-1 system. The cause was attributed to the 155,000 psi tensile strength of the 21-6-9 CRES tubing. Normally one swaging operating is sufficient to attach Deutsch fittings. Because of the tubing hardness, the supplier subsequently recommended 3 swages--120° apart. All Deutsch fittings in FC-1 and FC-2 were swaged 3 times and the proof test was completed satisfactorily.

Compatibility Test - No leakage was observed at any time during the 150 hour test at the following locations:

- All internally swaged joints (Resistoflex)
- All externally swaged joints (Deutsch)
- All heat shrink joints (Raychem)
- All broached/elastomer joints (Rosan)

Table 13. Fluid Contamination Checks

System	Test Hours	Micron Size Range					
		5-15	15-25	25-50	50-100	100+	
FC-1							
*		4829	162	15	0	0	System Clean-up
*	0	10153	269	41	6	1	
*	50	4979	152	46	3	0	
*	100	10547	435	82	2	0	
*	150	3284	118	17	2	1	
FC-2							
**		1651	113	60	17	1	System Clean-up
**	0	1558	47	6	0	0	
**	50	903	16	4	0	0	
*	100	6353	1204	150	5	2	
*	150	53728	597	30	2	1	

*Fluid sample taken upstream of return filter.

**Fluid sample taken downstream of return filter.

Reference Standard

NAS 1638	Class 8	64,000	11,400	2025	360	64

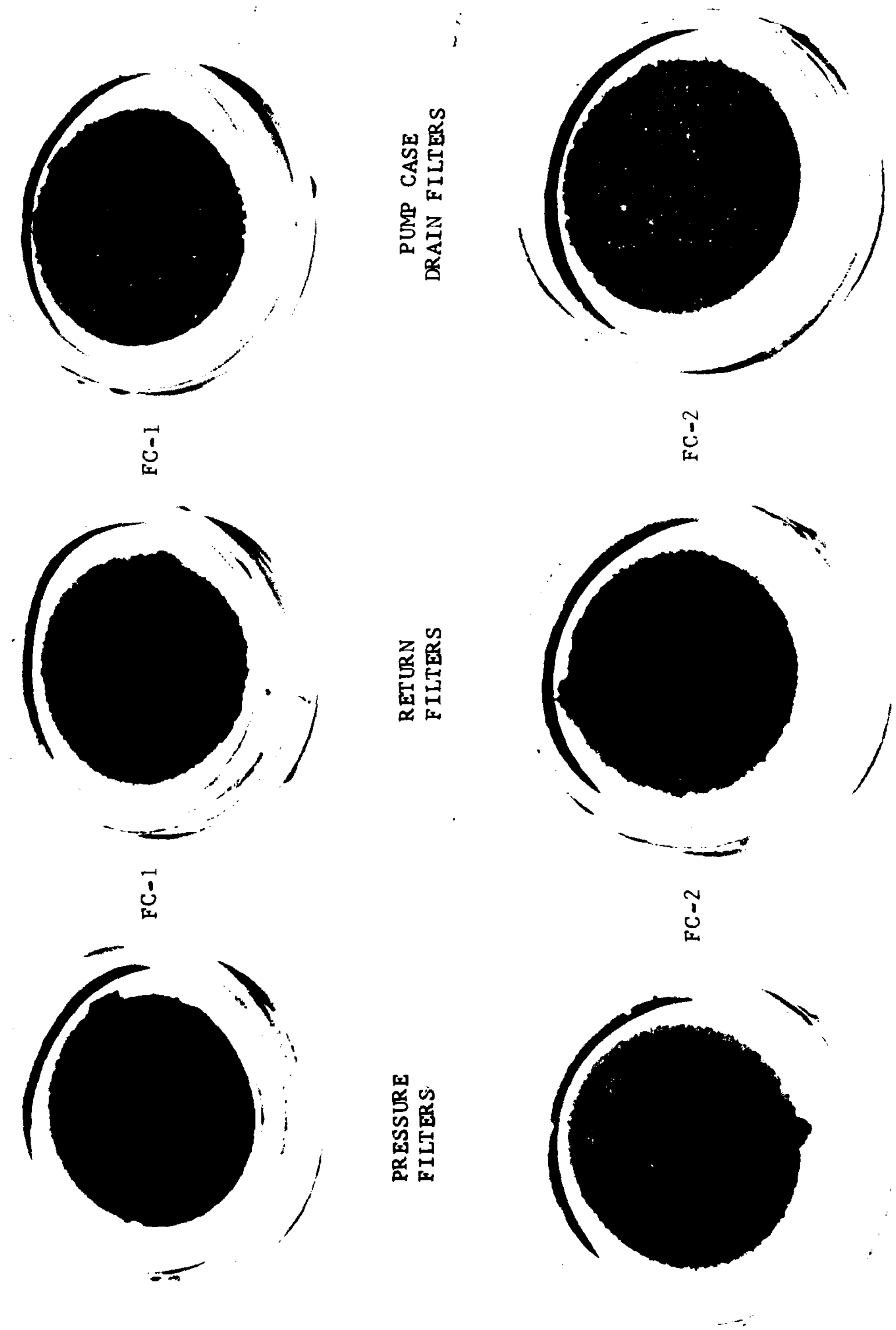


FIGURE 54. Filter patches at 150 hours

Table 14. Pump Case Drain Filter Element Changes

Compatibility Test Time, Hr.	Total Operating Time on Element, Hr.	Element* Changed
45.7 **	73.1**** 65.3	FC-1 FC-2
70.0	24.3 24.3	FC-1 FC-2
102.5***	32.5 32.5	FC-1 FC-2
129.7	27.2 27.2	FC-1 FC-2

*All elements were APM P/N AC-7031F-697Y6 (M8815/18-1) with a 5 micron absolute filtration rating.

**Filter $\triangle$P indicators up; case drain pressure allowed to increase to 220 psig. All subsequent element changes made when filter $\triangle$P indicator operated.

***LHS "interim pumps" replaced with backup pumps.

****FC-1 system, only, used during math model tests. See section 6.0.

A slight seepage occurred at approximately 30% of the separable lip-seal type joints (both Resistoflex and Deutsch). The leakage rate was estimated to average about 1 drop/10 hours of test cycling. The cause was probably due to minute imperfections or scratches in the sealing surfaces.

5.3.6.5 LHS Fluid - Viscosity checks were made to provide an indication of the shear stability of MIL-H-83282 fluid. As shown on Table 16, no significant change was observed. The data has limited validity, however, because of the periodic additions of new fluid to FC-1 and FC-2 as discussed in paragraph 5.3.5.6.

The black particles observed on the filter patches (noted in section 5.3.6.3) were believed to be associated with the hydraulic fluid. A sample of black particles analyzed by the Rockwell International Science Center and reported in Reference 10 was found to be 99% carbon. Black particles were not observed during the 400 hour, 8000 psi seal test conducted by Vought, section 5.1. Formulation differences between the NAAD and Vought fluids is the most likely cause for the disparity in performance, although differences in operating conditions is a possible cause. Further investigation in this area is warranted.

5.3.6.6 LHS Relief Valves - FC-1 and FC-2 each had a relief valve to safeguard against system over-pressurization. Cracking pressure, reseat pressure, and internal leakage measured at the test check points are shown on Table 15. Valve performance was satisfactory.

5.3.6.7 LHS Restrictor - All flow cycling was performed during the third block of 50 hours (see section 5.3.5.3). A total of 3200 flow cycles were passed through the restrictor in each direction. Flow data are given on Table 17. Restrictor performance was satisfactory.

5.3.6.8 LHS 4-Way Solenoid Valve - Evaluation testing of the 4-way valve was not completed because of a failure. Test cycling was begun at the start of the third 50 hour block. The valve operated the speed brake for 1043 cycles at which time the valve ceased to function. The unit was returned to the supplier for failure analysis. A pin used to operate the pilot valve was found to be damaged; the cause was improper heat treatment of the pin. Compatibility test cycling was continued during this period using two 3-way solenoid valves to operate the speed brake actuator (see section 5.3.5.3). A total of 1682 cycles were run using the 3-way valves when the repaired 4-way valve was returned. The 4-way valve was then used to finish the required 3200 cycles on the speed brake actuator. A total of 1518 cycles were thus conducted on the 4-way valve.

Internal leakage was measured following completion of the compatibility test. With 8000 psi applied at port P, ports C1 and C2 blocked, room temperature leakage from port R was:

Operating Mode	Leakage, cc/min.
Solenoids #1 and #2 off	54.2
Solenoid #1 on	30
Solenoid #2 on	11.5

TABLE 15. Relief Valve Performance Summary

Valve Location	Test Hours	Cracking Press., psi Actual	Cracking Press., psi Required	Reseat Press., psi Actual	Reseat Press., psi Required	*Internal Leakage Actual	*Internal Leakage Required
FC-1 (M/N 1257)	0	8500	8500±100	8350	8300±100	1 drop/min.	
	50	8750		8700		**trace	
	***100	--		--			
	150	8900		8850		2 drops/min.	
FC-2 (M/N 1258)	0	8400		8300		4 drops/min.	
	50	8350		8300		9 drops/min.	
	100	--		--		--	
	150	8500		8450		**trace	

*Room temperature leakage with 8000 psi applied to inlet port

**Leakage insufficient to form a drop

***100 hour performance check not conducted

* TABLE 16.

Fluid Viscosity Summary

Test Hours	**Fluid Viscosity, cs FC-1	FC-2
0	15.49	15.35
50	15.35	15.35
***100	-	-
150	15.02	15.27

*See section 5.3.5.6 for discussion of make-up fluid

**Viscosity at atmospheric pressure and +100°F

***Viscosity check not made at 100 hours

TABLE 17. Restrictor Performance Summary

Test Hours	Flow Direction	**Flow, gpm Actual	Required
0	*Retract	3.80	4.0 ± 0.2
	*Extend	3.94	4.0 ± 0.2
50	-	-	
	-	-	
***100	-	-	
	-	-	
150	Retract	3.88	4.0 ± 0.2
	Extend	3.75	4.0 ± 0.2

*Retract speed brake
Extend speed brake

**Compressed flow at 7850 psi

***Restrictor not used during first 100 hours (see section 5.3.5.3)

Maximum allowable internal leakage is 20 cc/min. Internal leakage can be reduced to acceptable levels by minor rework.

5.3.6.9 Miscellaneous Components - Performance observations were used to evaluate LHS components on which performance tests were not run.

LHS Accumulator - The accumulator was charged with 2300 psi of nitrogen prior to compatibility test cycling. Pressure in the accumulator after completion of the compatibility test was 2300 psi (total elapsed time: 80 days). Performance was satisfactory.

LHS Check Valves - Four -8 size and two -3 size check valves were utilized in the test systems. Performance of all units was satisfactory.

LHS Pressure Gage - The gage was used to measure accumulator gas pressure and indicated 8250 psi when system pressure was 8000 psi. At 91.5 hours, the dial face and cover glass were observed to be loose. Performance was satisfactory, otherwise.

LHS Pressure Transmitters - FC-1 and FC-2 power modules each had a pressure transmitter. Readout was on a standard cockpit indicator with a dial remarked for 10,000 psi full scale, Figure 51. Indicated pressure averaged 7800 psi when system pressure was 8000 psi. Transmitter performance was satisfactory throughout the compatibility test.

LHS Pressure Snubber - A snubber was used to protect the pressure transmitters. Performance was satisfactory.

LHS Quick Disconnects - A coupled disconnect was on the discharge port of each pump; a bulkhead half disconnect with a dust cover was installed in each power module as a ground service connection. Performance of all disconnects was satisfactory.

LHS Tubing - 21-6-9 CRES tubing sizes utilized in the test systems were: 3/16 x .020, 1/4 x .023, 3/8 x .034, and 1/2 x .046. Tubing performance was satisfactory.

5.3.6.10 System Performance

Temperatures - Sixteen temperatures were monitored: 15 fluid temperatures and ambient, reference Table 7. Room temperature was generally in the range of +80 to 90°F. System fluid temperatures varied with the cycling schedule; typical values are listed on Table 18. Pump inlet fluid temperature was controlled at +180°F and +200°F during the first 50 hour block, reference Table 8. Pump inlet temperatures were maintained at +180°F continuously beginning at 50 hours because of the "interim pump" difficulties which occurred. Pump case drain temperatures were not allowed to exceed +275°F.

TABLE 18. Typical Temperature Data

			ACTUATOR LOAD/STROKE MAGNITUDE			
			2%	10%	50%	100%
SEQUENCE STEP NO. (SEE TABLES 8 AND 9)			2-7	2-6	4-5	6-3
T1	FC-1	RESERVOIR OUTLET	198	202	200	206
T2	FC-1	PUMP INLET	198	202	200	206
T3	FC-1	PUMP OUTLET	98	96	92	82
T4	FC-1	PUMP CASE DRAIN	248	268	270	275
T5	FC-1	HEAT EXCHANGE OUTLET	169	180	160	143
T6	FC-2	RESERVOIR OUTLET	196	197	194	193
T7	FC-2	PUMP INLET	200	200	199	199
T8	FC-2	PUMP OUTLET	196	202	202	199
T9	FC-2	PUMP CASE DRAIN	265	274	274	276
T10	FC-2	HEAT EXCHANGE OUTLET	204	191	185	178
T11	FC-2	RUDDER ACTUATOR RETURN	183	129	173	159
T12	FC-1	UHT ACTUATOR RETURN	168	172	180	183
T13	FC-2	AFCS ACTUATOR RETURN	228	228	229	225
T14	FC-2	AILERON ACTUATOR RETURN	193	158	188	190
T15	FC-1	SPEED BRAKE ACTUATOR RETURN	-	-	-	-
T16	-	AMBIENT	91	90	86	82

NOTE: DATA TAKEN DURING FIRST BLOCK OF 50 HRS.

Pressures - Dynamics in FC-1 and FC-2 pressure systems were sensed by a transducer located immediately downstream of the pump and by a transducer located just upstream of the UHT actuator. Pressure ripple was generally less than the maximum allowable ± 200 psi near the pumps and much less near the UHT actuator, Figure 55. This data was corroborated by the Air Force Flight Dynamics Laboratory, (see section 6.4). No serious hydraulic resonance was observed in FC-1 or FC-2 over a pump speed range of 2000 to 6000 rpm.

5.3.7 Test Summary

The 150 hour, 800,000 cycle compatibility test was completed satisfactorily, except for a number of minor problems. The test systems were stable, actuator operation was satisfactory, and pressure fluctuations were low. The results provide convincing evidence that the Phase II simulator should function as designed.

A summary of the malfunctions which occurred in FC-1 and FC-2 pressure systems during the compatibility test is presented on Table 19. All of the malfunctions were considered to be the result of normal development problems. Although additional minor problems may surface as the LHS program progresses, no major state-of-the-art development problems are anticipated.

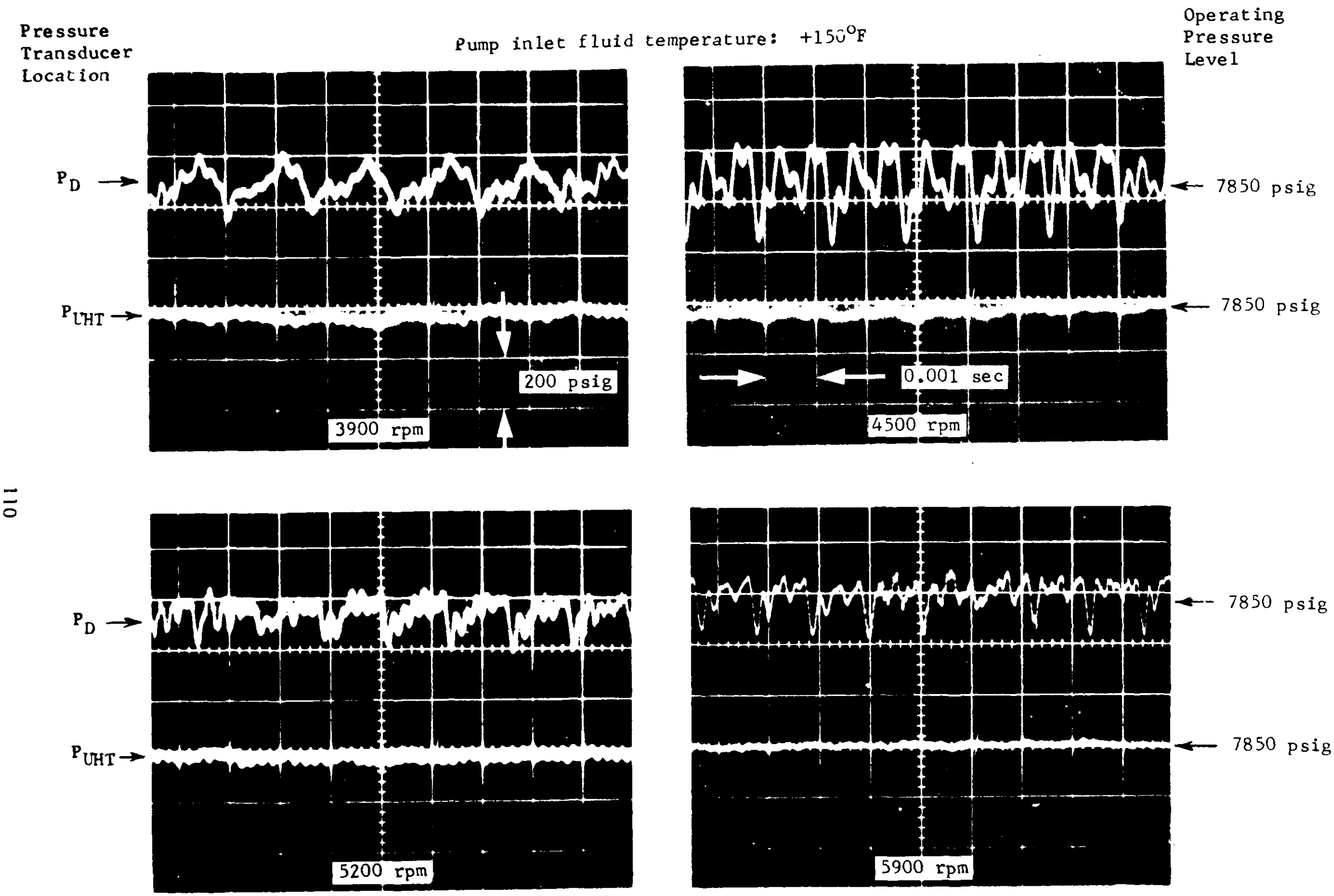
5.4 PRESSURE IMPULSE TEST

5.4.1 Test Procedure

A setup was built utilizing the following LHS components (see Figure 56):

- 3-way solenoid valve, Bendix P/N 3321473
- Quick disconnect, Aeroquip P/N AE80943H with dust cover
- Hose, Titeflex P/N 78570
- Tubing, 21-6-9 CRES, -3 and -8 sizes
- Fittings: Deutsch, Raychem, Resistoflex (see Table 20).

Pressure impulses were generated by suddenly porting fluid at 8000 psi into a closed system containing fluid at return pressure. A 125 in^3 fluid volume teed into the pressure system was used as an accumulator to assist in providing high instantaneous fluid velocities. The surge was sensed by a pressure transducer and recorded photographically on an oscilloscope. The test consisted of applying 40,000 pressure impulses (20% of qualification test requirements) peaking at 10,800 psi (135% of system pressure) at the rate of 60 cpm. Cycling was conducted with a fluid temperature of $+110^{\circ}F$.



P_D = 34 inches downstream of FC-1 pump discharge port P_{UHT} = 44 inches upstream of UHT actuator FC-1 pressure port

FIGURE 55. System pressure ripple

Table 19. Summary of LHS Malfunctions and Failures

Test Hours Completed	Component	Remarks
39.3	Static O-ring on FC-1 8000 psi filter inlet port	Dynatube adapter fitting had rough surface where O-ring sealed.
45.7	Static O-ring on FC-2 MS bulkhead fitting near P5 pressure transducer	Low pressure leak occurred over week-end. Reservoir bootstrap pressure caused fluid loss. O-ring had permanent set.
50	FC-1 pump	Excessive case flow developed during 50 hr. performance check. Part of one piston shoe was missing due to brazing voids.
56.2	FC-1 pump	Pin hole leak developed in aluminum valve block.
102.6	FC-2 pump	External leak developed in joint between valve block and housing due to erosion pitting of O-ring gland in aluminum valve block.
119.0 19 hrs on valve	4-way solenoid valve	Valve stopped operating at 1043 cycles due to damaged pin in pilot valve. Pin not heat treated properly.
128.9	AFCS actuator	Cylinder #2 piston operation became rough. Internal binding suspected. Cause to be determined when actuator is disassembled. Test continued using Cylinder #1.

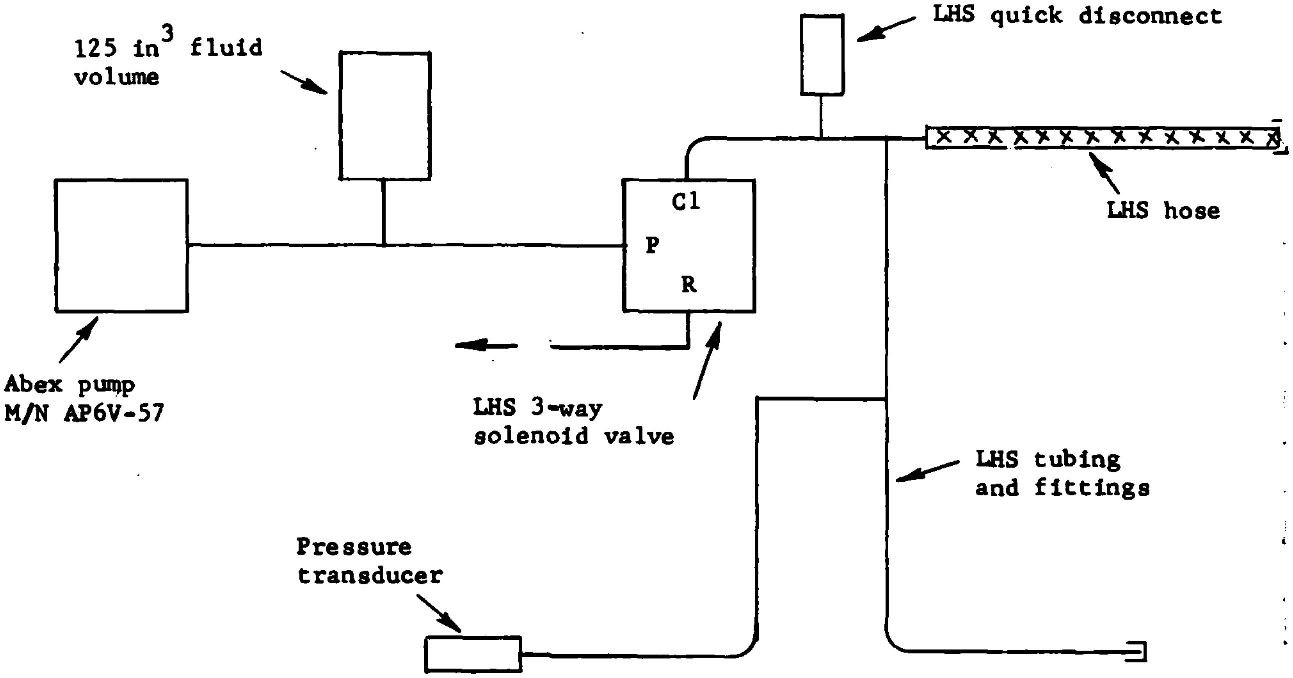


FIGURE 56. Pressure impulse test, original configuration

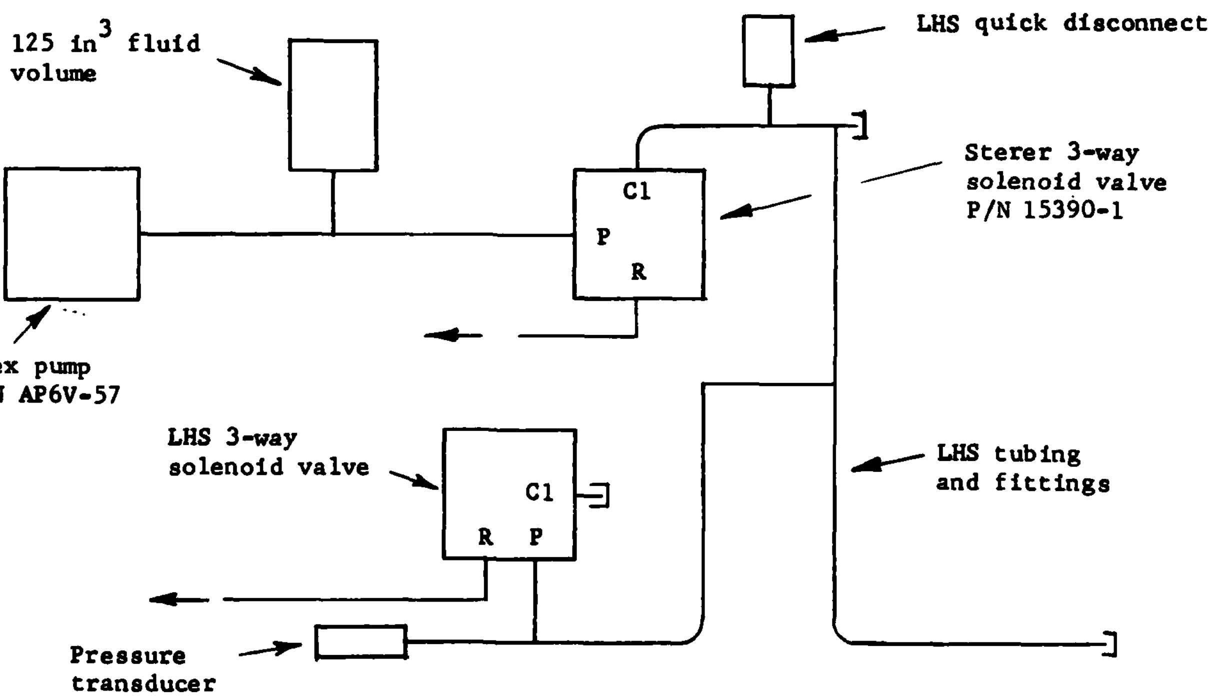


FIGURE 57. Pressure impulse test, final configuration

Table 20. Fittings Pressure Impulse Tested

Manufacturer	Description	Part Number	Quantity
Deutsch	Tee	DNR10023-080803	1
Resistoflex	Coupling	R44101T-03	1
Resistoflex	Elbow	R44129-90T-03	1
Resistoflex	Tee	R44130T-08	1
Resistoflex	Tee	R44133T-03	1
Resistoflex	Connector, Female	R44296T-03	2
Resistoflex	Elbow	R44360T-08	1
Resistoflex	Connector, Male	R54100T-03	1
Resistoflex	Connector, Male	R54100T-08	1
Resistoflex	Connector, Female	R54045T-03	1
Resistoflex	Connector, Female	R54045T-08	3
Raychem	Coupling	3P00101-2	2
Raychem	Coupling	3P02121-8	1

The required pressure impulse of 10,800 psi could not be attained with the test setup shown on Figure 56; the surges were too small. Several configuration changes were made in an attempt to increase the surge.

Configuration	Maximum Impulse Pressure Attained
1. Original setup	8400 psi
2. LHS hose removed from setup	9600 psi
3. LHS 3-way solenoid valve replaced with LHS 4-way valve (4-way valve has larger internal porting than 3-way)	9800 psi
4. LHS 4-way solenoid valve replaced with Sterer 3-way valve, see section 5.3.5.4. (Sterer valve has larger internal porting than LHS 4-way valve)	10,600 psi

The configuration used for the pressure impulse test is shown on Figure 57. Deviations from the planned test are summarized below:

- The LHS hose was not used in the test system because of its surge damping characteristics.
- The LHS 3-way valve contained restrictions which limited surge development when it was cycled. The valve was therefore plumbed into the system so that its pressure port was subjected to the test surge. The valve was de-energized throughout the impulse test.
- A 3-way solenoid valve, Sterer P/N 15390-1, was used to port pressure into and out of the test setup. The Sterer valve had larger internal porting than the LHS 3-way valve, permitting the passage of higher fluid velocities.

Photographs of the test setup and pressure impulse wave form are shown on Figures 58 and 59.

5.4.2 Test Results

The 40,000 cycle test was completed uneventfully. All fittings performed satisfactorily except for a slight seepage observed at several separable fitting lip seal joints, see compatibility test, section 5.3.6.4. No external leakage was observed at the LHS 3-way valve or quick disconnect. Two failures were found, however, during component checkouts following completion of the impulse test. These are discussed in the next sections.

FIGURE 58. Pressure impulse test setup

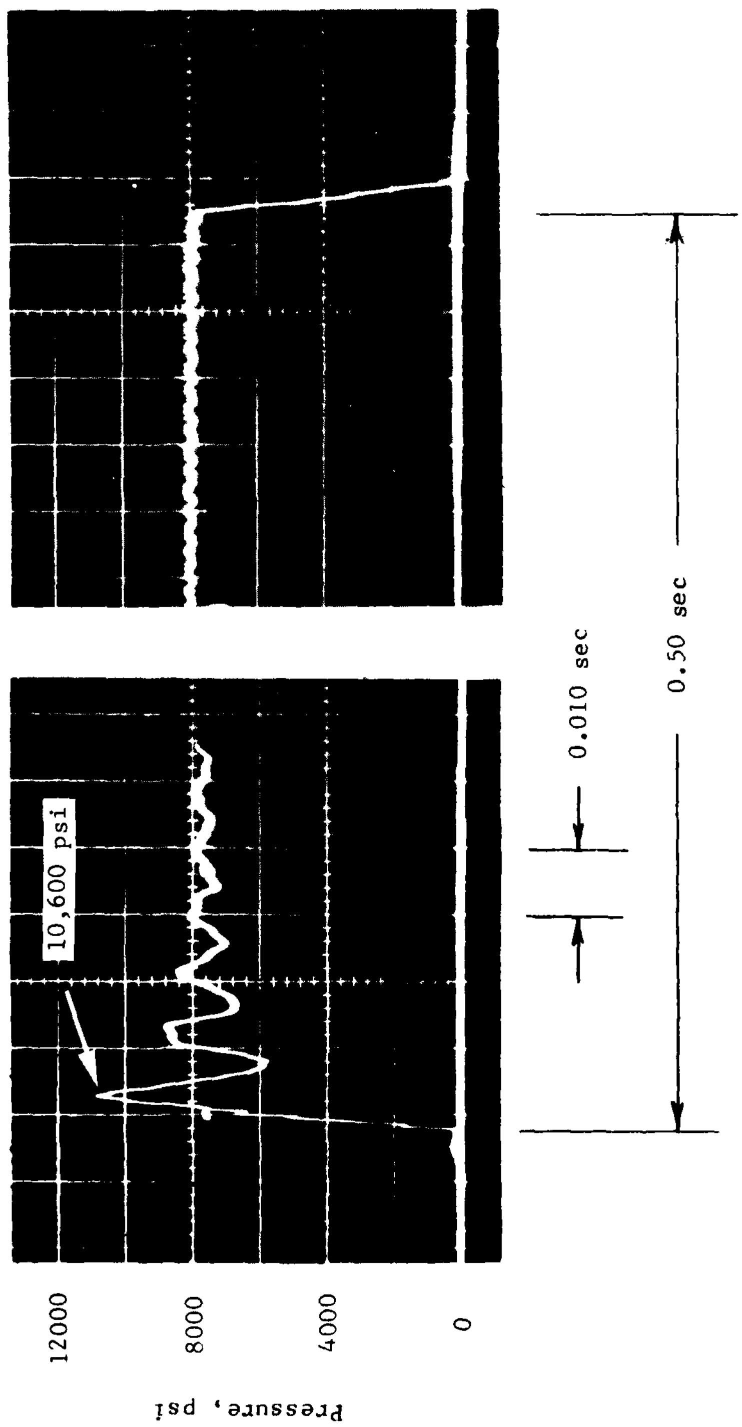


FIGURE 59. Pressure impulse wave form

LHS 3-Way Solenoid Valve - The valve functioned satisfactorily before the impulse test, but was inoperative following the test. Internal leakage measured before the impulse test was 9.6 cc/min.; after the test it was 1.5 cc/min. The valve was returned to the supplier for disassembly and failure analysis. The failure was caused by lack of heat treatment of the pilot pin.

LHS Quick Disconnect - When the protective dust cover was removed for examination of the disconnect, the porting valve was found to have failed. The time of failure was not known since there was no external evidence of a problem. The failure occurred in the web areas between the four porting holes in the steel valve.

The LHS quick disconnect specification, LHS-8828, was examined, and it was found that only coupled disconnects have pressure impulse test requirements; aircraft-half ground service disconnects (with dust covers) have no impulse test requirements. This omission was also present in the 3000 psi quick disconnect specification, MIL-C-25427. Performance requirements for aircraft-half ground service disconnects should be addressed in both specifications. The LHS disconnect specification will be updated in Phase II.

5.5 COMPONENT ENDURANCE TEST

5.5.1 Test Procedure

The test setup contained the following LHS components (see Figure 60):

*Accumulator, Bendix P/N 3321471

Check Valves, *Gar-Kenyon P/N 95202-1
*Gar-Kenyon P/N 95202-5
**Circle-Seal P/N P2-858

Hose, Titeflex P/N 78570

*Manifold, CAAD P/N 8696-581201

*Pressure gage, Q-E-D P/N 1218-63-1

*Relief Valve, PneuDraulics P/N 1257

*4-Way Solenoid Valve, Bendix P/N 3321472

*Component previously used in compatibility test setup, section 5.3.
**Circle-Seal Controls, Anaheim, CA, provided this unit for evaluation testing.

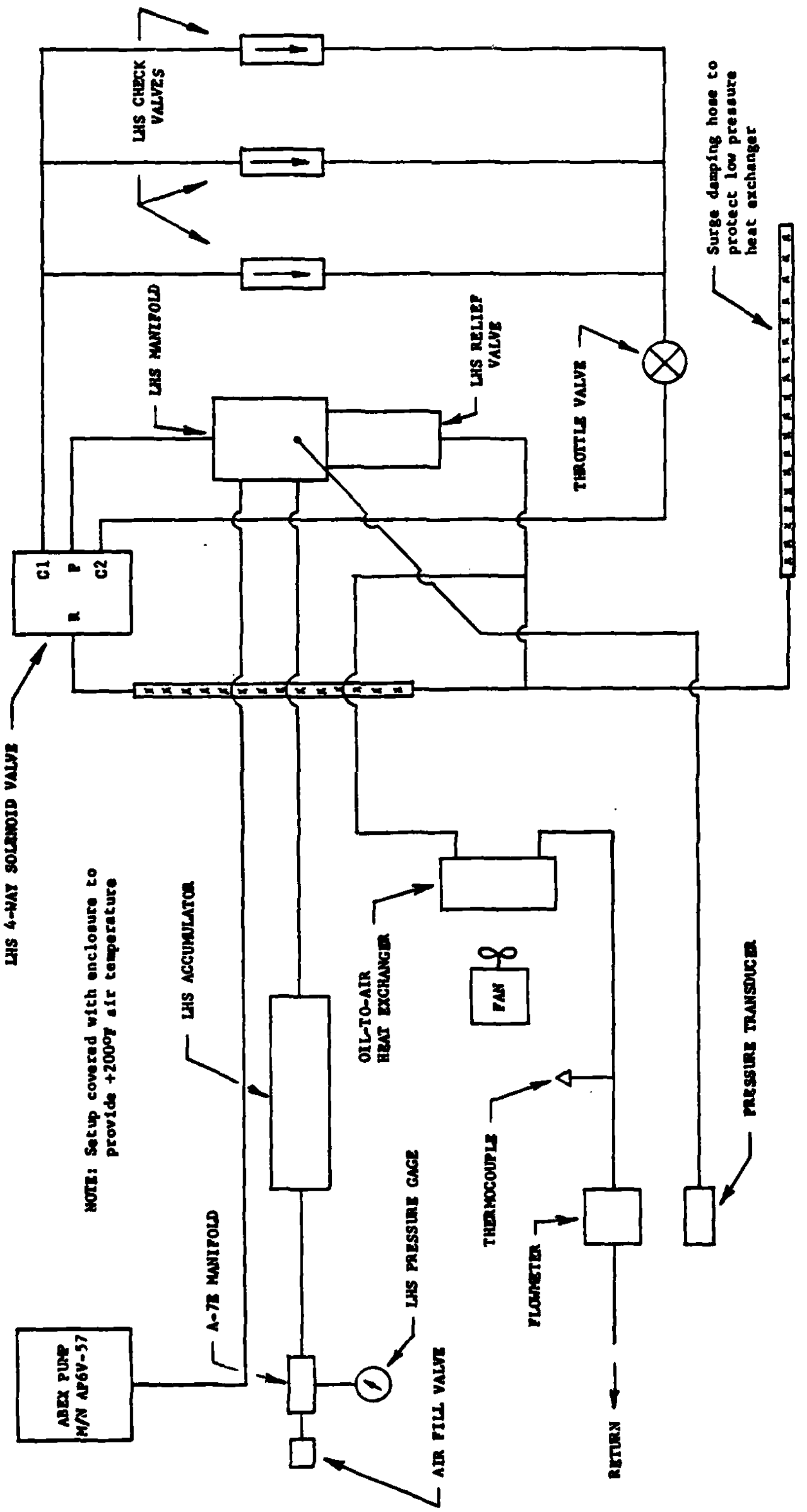


FIGURE 60. Component endurance test, original configuration

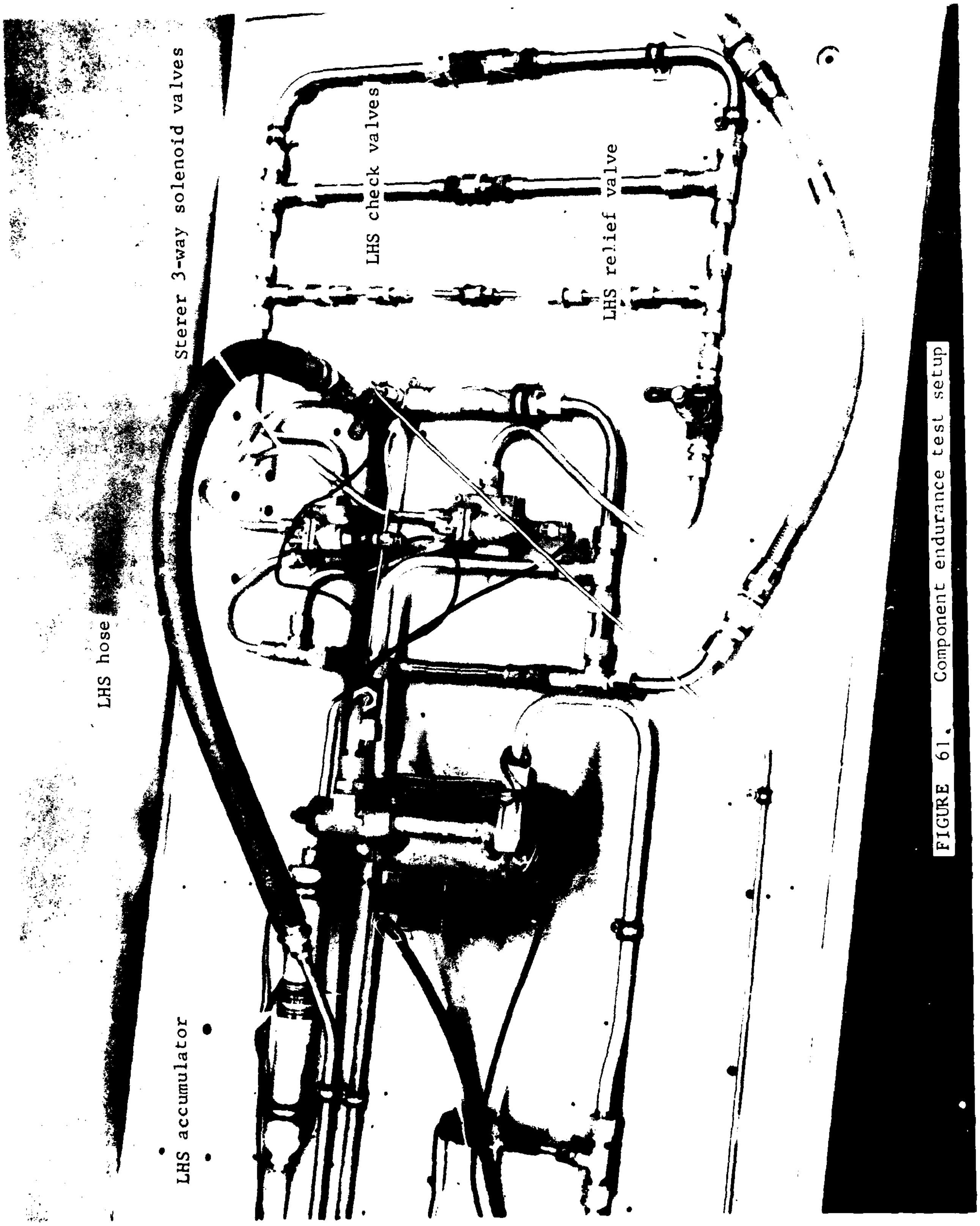


FIGURE 61. Component endurance test setup

System pressure was cycled from 7000 psi to 9000 psi using the 4-way solenoid valve, a throttle valve set for 7000 psi, and the pump compensator set at 9000 psi. Pressure was 7000 psi in the free-flow direction through the check valves, and 9000 psi in the checked direction. The 9000 psi level opened the relief valve, and the 7000/9000 psi levels cycled the accumulator piston and pressure gage. Total flow was 4 gpm through the check valves and 2 gpm through the relief valve. The test consisted of applying 10,000 pressure cycles (20% of qualification test requirements) at the rate of 2 seconds at 7000 psi and 2 seconds at 9000 psi. Cycling was conducted with fluid and air temperatures of +200°F following a warm-up period.

A static seal in check valve P/N 95202-5 failed at 826 cycles. This valve (item 49 on Figure 5) was replaced with check valve P/N 95201-5 (item 52 on Figure 5) to complete the endurance test.

The 4-way solenoid valve stopped operating at 3000 cycles and was returned to the supplier for disassembly and failure analysis (see section 5.3.6.8). The test was completed using two 3-way valves, Sterer P/N 15390-1, to replace the 4-way valve. This final configuration is shown in Figure 61.

5.5.2 Test Results

LHS component performance is summarized on Table 21. The test was interrupted three times during the 10,000 cycles; two seals failed and the 4-way valve malfunctioned. As noted on Table 21, the failures were the result of design deficiencies and can be corrected.

TABLE 21. LHS Component Endurance Test Summary

Component	Cycles Completed	Remarks
Accumulator	10,000	1. Satisfactory performance 2. 2200 psi nitrogen precharge held without leakage
Check Valves P/N 95202-1	10,000	1. Satisfactory performance 2. Internal leakage after test: None
P/N 95202-5	826	1. Diametral seal extruded out 2. Recommended design changes: -Increase overlap at seal diametral clearance -Increase assembly torque -Install lockwire on valve
*P/N 95201-5	9174	1. Poppet failed 2. Recommended design change: -Increase web areas between porting holes
P/N P2-858	10,000	1. Satisfactory performance 2. Internal leakage after test: None
Hose	7,000	1. Satisfactory performance 2. Installed at 3000 cycles
Manifold	10,000	1. Satisfactory performance
Pressure gage	10,000	1. Satisfactory performance
Relief Valve	10,000	1. Satisfactory performance 2. After test data: Cracking pressure: 8575 psi Reseat pressure: 8400 psi Internal leakage: 1 drop/min
4-Way Solenoid Valve	3,000	1. Stopped operating 2. Recommended design change: -Relocate cross-drilled flow passage in pilot valve
**Air Fill Valve, MS 28889	800	1. Face seal extruded out, valve not tight in boss 2. New seal installed, valve tightened, and 9200 cycles completed satisfactorily

*Used to replace P/N 95202-5.

**Valve designed for 5000 psi service. An LHS fill valve was not used. The LHS valve (when procured) is recommended to have a boss type seal instead of a face seal.

6.0 MATH MODEL

6.1 INTRODUCTION

The analytical approach used to model the test system was based upon application of computer programs developed for the Air Force, Reference 18. These programs evolved from a major contracted study by McDonnell Aircraft Company and are considered the best validated methods developed to date for dynamic modeling of complex hydraulic systems. The Air Force has made this information available to industry. Three computer programs are involved:

1. Hydraulic System Frequency Response (HSFR) - This program predicts resonant frequencies, locations, and amplitudes of standing wave oscillatory flows and pressures resulting from the operation of aircraft piston-type pumps.

2. Hydraulic Transient Analysis (HYTRAN) - This program simulates the dynamic response of a hydraulic system to sudden changes in load flow demand, and predicts the pressure and flow disturbances which propagate through the system.

3. Hydraulic Transient Thermal Analysis (HYTTHA) - This program predicts the effects of heat generation, dissipation, and temperatures on a hydraulic system.

References 18 through 21 contain background and user information necessary to implement the above programs.

The laboratory test system--consisting of power generation, power transmission, and actuation systems--was modeled for the HSFR computer program. Analytical data obtained from the program were compared with test data to verify the predictive capabilities of the program and to determine the most suitable test procedures.

6.2 FREQUENCY RESPONSE ANALYSIS VERIFICATION

6.2.1 Background

Aircraft piston-type pumps cause pressure and flow oscillations (commonly known as pump ripple or pulsations) to be imposed upon the pressurized hydraulic fluid. Since the pulsations are in the audio frequency range, they are termed acoustic noise. This pump induced acoustic noise can generate standing waves of pressure and flow throughout the pressure system in a manner similar to those observed in organ pipes and electrical transmission lines. When the pulsation frequency coincides with natural frequencies in the system, hydraulic resonance occurs. This creates large pressure peaks and destructive vibratory conditions can result.

The HSFR program computes pump speeds for which hydraulic resonances occur at element locations in the system. Component modifications can be rapidly evaluated to correct unacceptable resonant conditions. Potential problems resulting from pump acoustical noise can therefore be minimized in the design stage.

6.2.2 Test System

The system evaluated was FC-1, Figure 5. A schematic diagram of the math model verification system is shown on Figure 62. Components are arranged and numbered according to the format described in Reference 18. There are 44 circuit/elements. Details of the pump, actuators, and other components are given in section 3.0.

Computer input data used to model the system is tabulated in Table 22; the format is given in Reference 18. The program permits the user to input physical properties of the hydraulic fluid, operating pressure, and fluid temperature. Bulk modulus values used for MIL-H-83282 at 8000 psi were 190,000 psi @ +200°F and 210,000 psi @ +145°F. A complete pump model was utilized (N-TYPE 9, K-TYPE 21). The pressure side of the reservoir was included as a loss-less volume. A block diagram of the math model test instrumentation is shown on Figure 63. System pressures were sensed by two strain gage type transducers teed into the hydraulic system; one located near the pump outlet port, the other just upstream of the UHT actuator. The transducer had a bandwidth of 20,000 Hz; the transducer amplifier had a bandwidth of 4000 Hz. System flow pulsations were not measured because flow sensors having the required performance characteristics--8000 psi operating pressure and 3000 Hz bandwidth--are not available.

Pressure pulsation harmonic frequencies were detected with a Federal Scientific M/N VA-500 Spectrum Analyzer, Figure 64. Signal input to the analyzer (from the pressure transducer amplifier) was observed on a monitor scope. Using a marker generator in the analyzer, first and second harmonic amplitudes were read on a display scope. Pump speed was indicated on a frequency counter in the control console, Figure 51. Harmonic determinations were made every 100 rpm over a pump speed range of 1700 to 6200 rpm.

Temperatures were measured with probe-type thermocouples teed into FC-1 plumbing. Fluid temperature was sensed at a location near the pump inlet, outlet, and case drain ports. Fluid temperature was maintained by automatic controls.

6.2.3 Test Results

Pressure and flow plots as a function of pump rpm were generated from the computer program. Figure 65 gives predicted peak pressure oscillations (single amplitude) at circuit element No. 8 (pressure transducer near pump). Figure 66 is a corresponding flow plot at element No. 8. A pressure plot at element No. 42 (pressure transducer near UHT actuator) is shown on Figure 67. The test conditions for these plots were:

Operating Pressure:	8000 psi
Flow:	0.2 gpm (actuator valves at null)
Fluid Temperature:	+145°F (pump outlet)

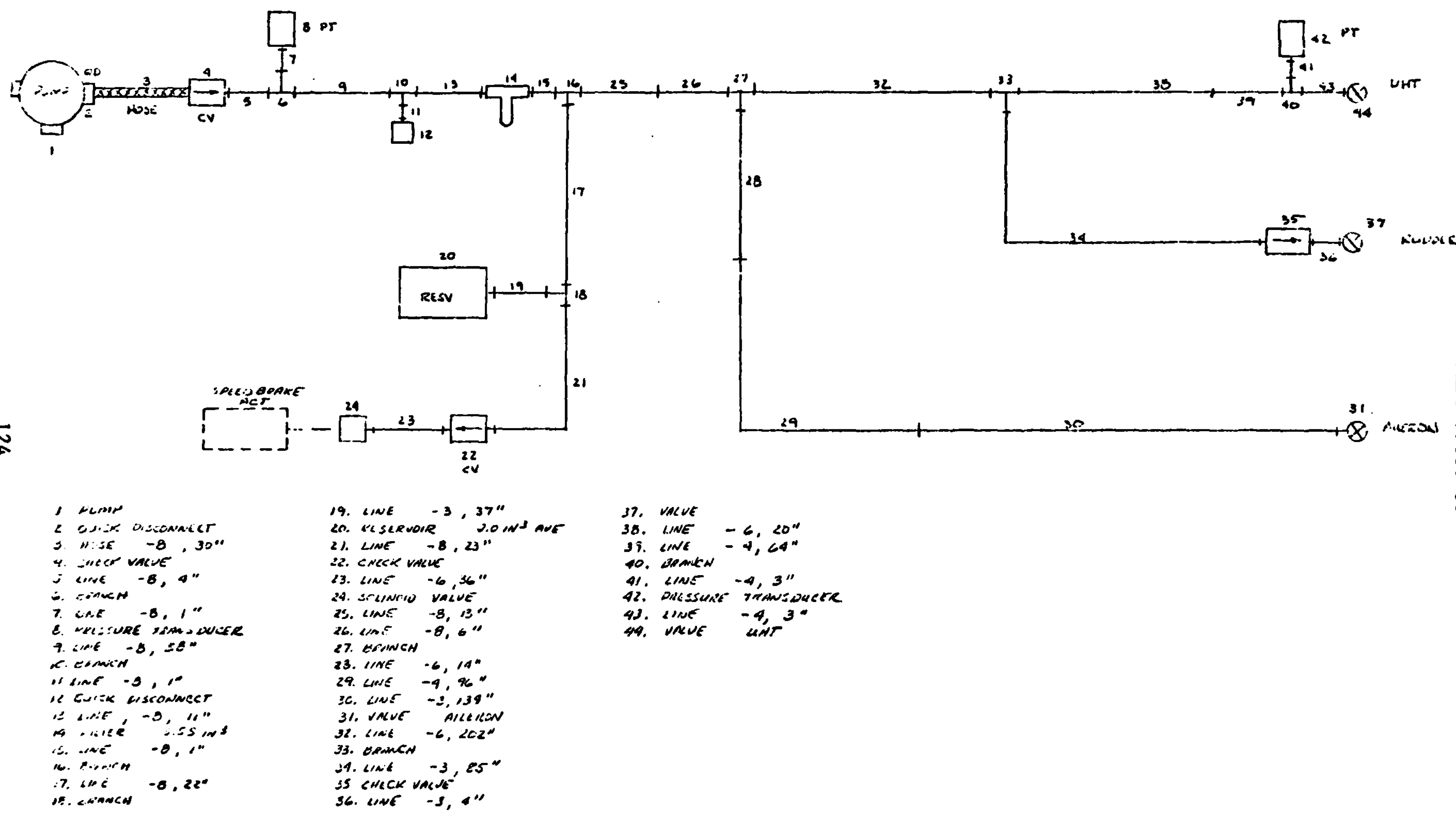


FIGURE 62. Math model verification system

TABLE 22. Computer Input Data

HYDRAULIC SYSTEM FREQUENCY RESPONSE PROGRAM

A7/LHS POWER SYSTEM COMPONENT EVALUATION USER RUN-1

RESPONSE IS CALCULATED FROM 100.00 TO 6000.00 R.P.M. IN INCREMENTS OF 100.00 R.P.M.

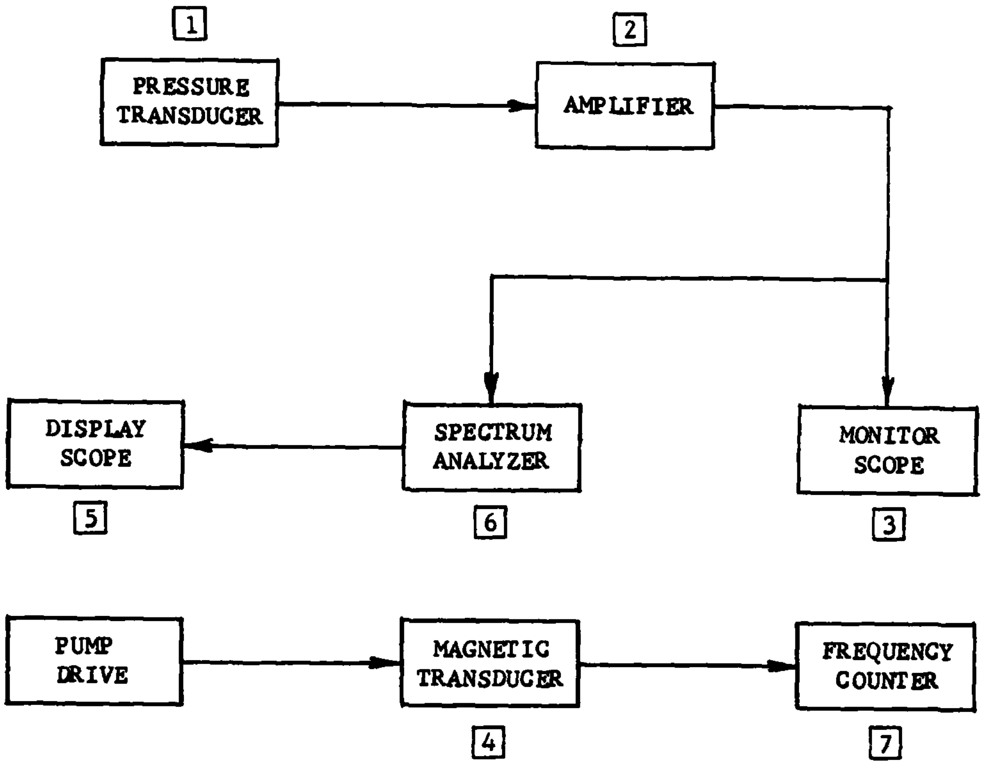
RESPONSE IS PLOTTED FOR THE -FIRST- HARMONIC FREQUENCY

NUMBER OF PUMPING ELEMENTS= 9.

FLUID DATA FOR MIL-H-83282/CAD 8000.0 PSIG AND 200.0 DEG F

VISCOSITY - .113E-01 IN**2/SEC
DENSITY - .775E-04 (LB-SEC**2)/IN**4
BULK MODULUS - .190E+06 PSI

ELEMENT NUMBER	****SYSTEM ELEMENT INPUT DATA****									
	N TYPE	K TYPE	....PHYSICAL DATA....							
1	9	21	.090	.443	.807	.850	.429	.062	.090	
			.09030	12.00000	4.20000	3.25000	28.00000	30.20000	28.00000	22.00000
			85.00000	.06000	.30820	1.45000	.00021	30.00000	60.00000	.30600
2	7	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
3	1	1	30.000	.454	0.000	140000.000	0.000	0.000	0.000	
4	4	0	.038	0.000	0.000	0.000	0.000	0.000	0.000	
5	1	0	4.000	.500	.046	28000000.000	0.000	0.000	0.000	
6	6	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
7	1	0	1.000	.500	.046					
7	1	0	1.000	.500	.046	28000000.000	0.000	0.000	0.000	
8	13	0	.010	0.000	0.000	0.000	0.000	0.000	0.000	
9	1	0	58.000	.500	.046	28000000.000	0.000	0.000	0.000	
10	6	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
11	1	0	1.000	.500	.046	28000000.000	0.000	0.000	0.000	
12	13	0	.010	0.000	0.000	0.000	0.000	0.000	0.000	
13	1	0	11.000	.500	.046	28000000.000	0.000	0.000	0.000	
14	3	0	5.550	0.000	0.000	0.000	0.000	0.000	0.000	
15	1	0	1.000	.500	.046	28000000.000	0.000	0.000	0.000	
16	6	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
17	1	0	22.000	.500	.046	28000000.000	0.000	0.000	0.000	
18	6	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
19	1	0	37.000	.189	.020	28000000.000	0.000	0.000	0.000	
20	13	0	2.000	0.000	0.000	0.000	0.000	0.000	0.000	
21	1	0	23.000	.500	.046	28000000.000	0.000	0.000	0.000	
22	3	0	.010	0.000	0.000	0.000	0.000	0.000	0.000	
23	1	0	36.000	.375	.034	28000000.000	0.000	0.000	0.000	
24	13	0	.001	0.000	0.000	0.000	0.000	0.000	0.000	
25	1	0	13.000	.500	.046	28000000.000	0.000	0.000	0.000	
26	1	0	6.000	.500	.046	28000000.000	0.000	0.000	0.000	



1 Pressure transducer, Viatran M/N 122EF76

2 Amplifier, Viatran M/N 602

3 Oscilloscope, Tektronix Type 545A

4 Magnetic transducer, Electro Products M/N 3010-AN

5 Oscilloscope, Tektronix Type 502A

6 Spectrum analyzer, Federal Scientific M/N VA-500

7 EPUT and timer, Beckman M/N 6147

FIGURE 63. Math model test instrumentation

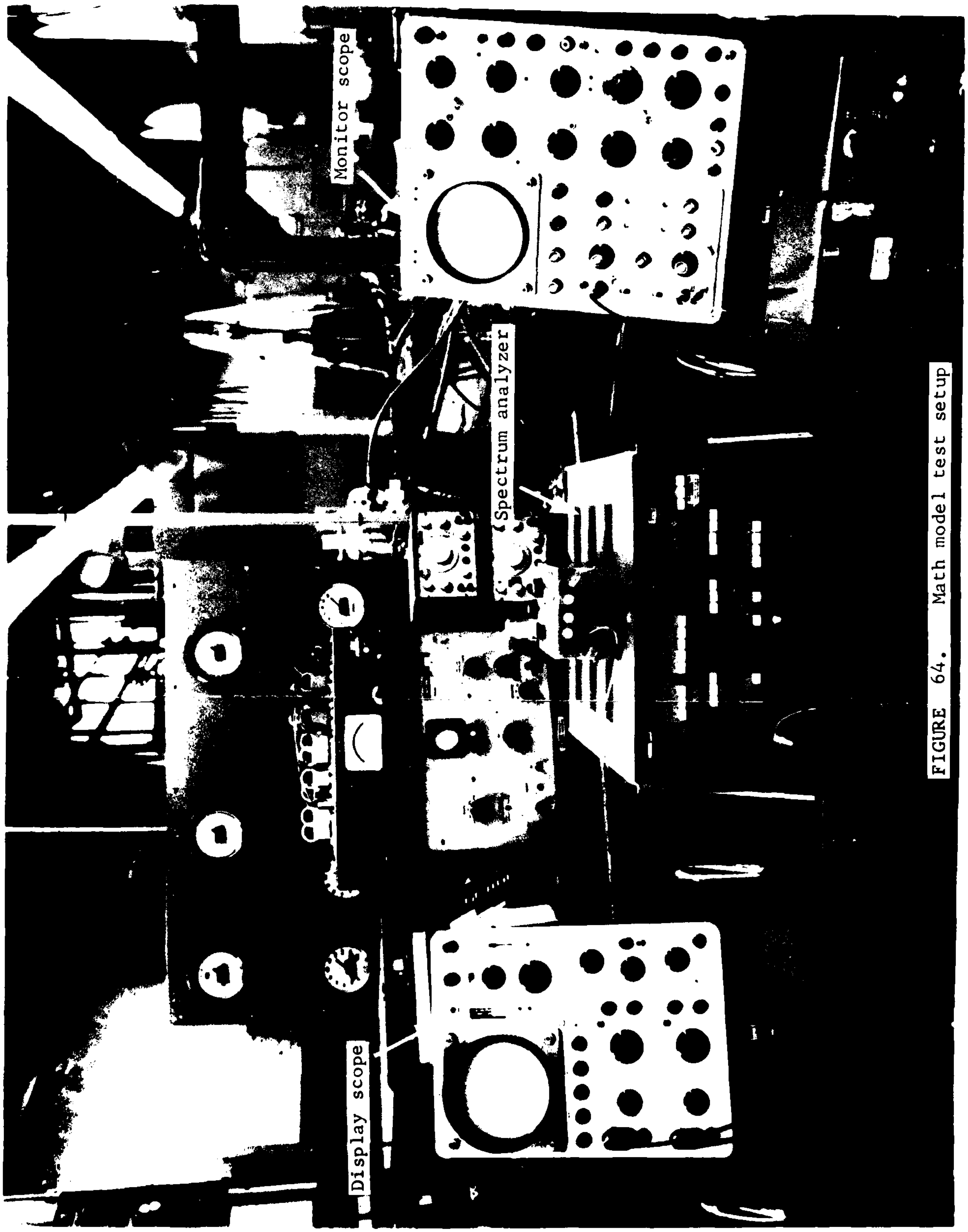


FIGURE 64. Math model test setup

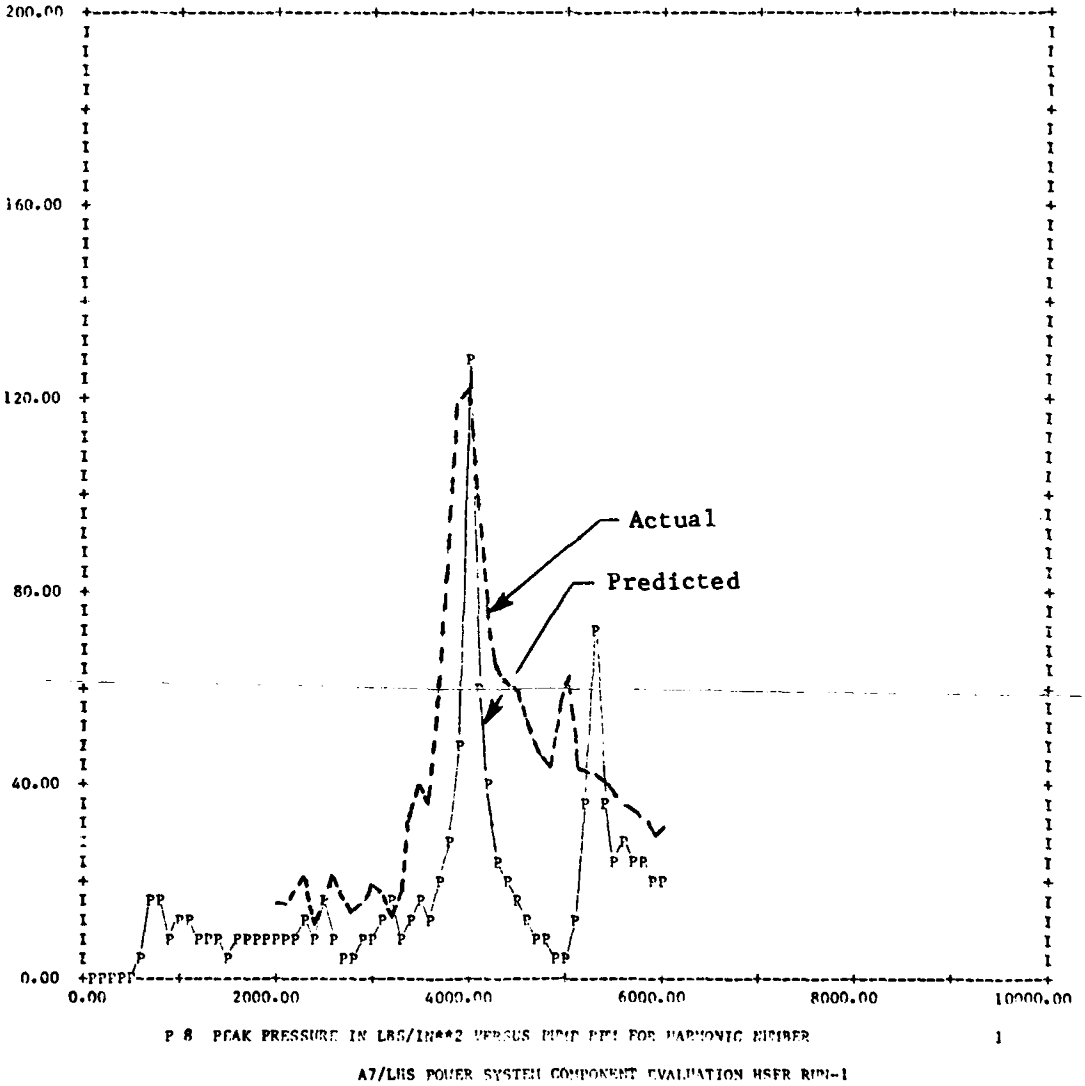


FIGURE 65. Peak pressure at P8, 1st harmonic

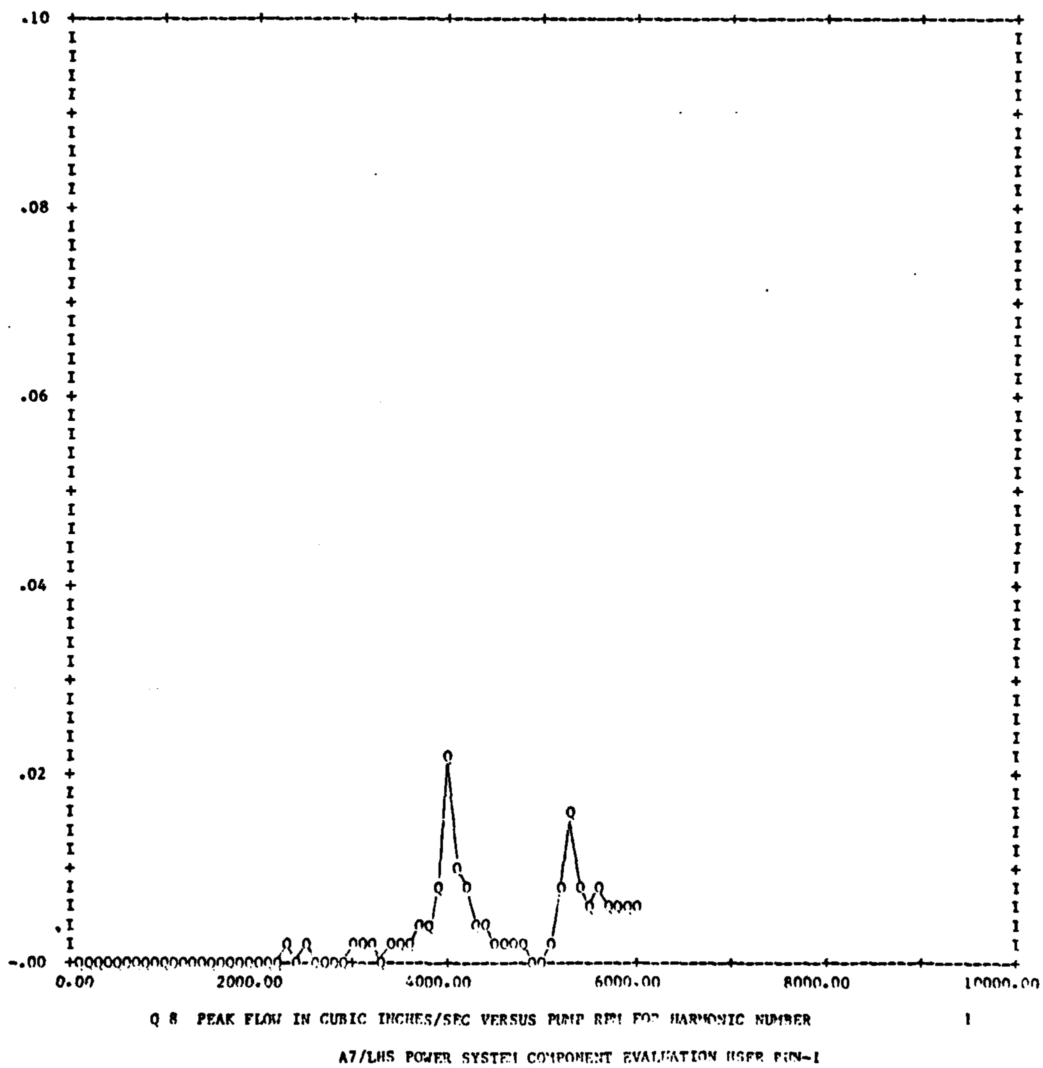


FIGURE 66. Peak flow at Q8

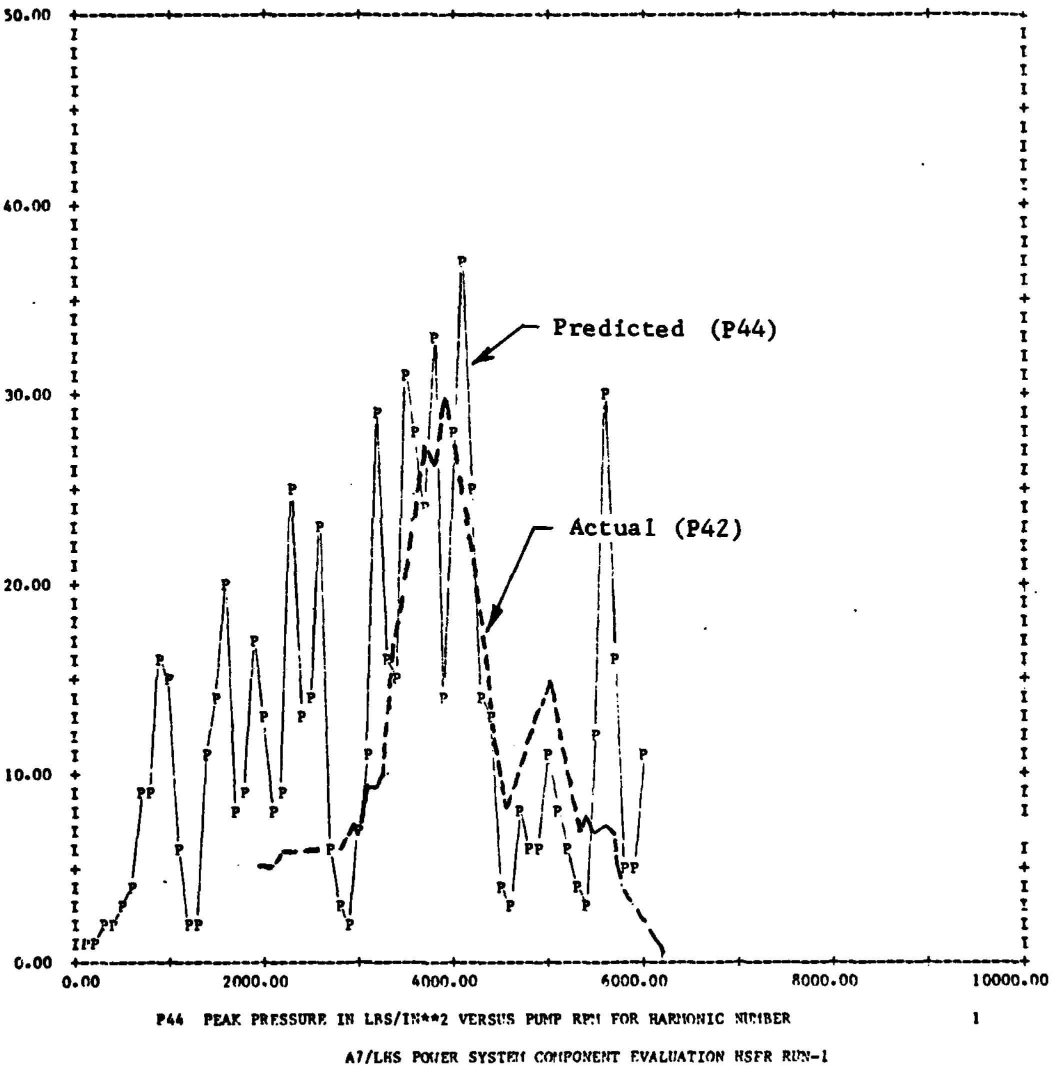


FIGURE 67. Peak pressure at P42 and P44, 1st harmonic

Spectrum analyzer data covering the first harmonic are shown on Figures 65 and 67. The measured data correlates well with the calculated data at element No. 8. Less correlation occurred at element No. 42. This was attributed to differences in fluid temperature due to the low flow rate and to marginal signal-to-noise ratios produced by the very small pressure pulsations occurring at element No. 42.

Comparison of measured and calculated second harmonic data at element No. 8 is given on Figure 68. The resonant speed conditions were predicted well, but the calculated amplitudes were much higher than the observed amplitudes.

The foregoing tests were repeated except the pump outlet temperature was increased to +200°F. First harmonic data correlated well with the predicted at 3900 rpm, but there was significant separation at higher speeds, Figure 69. Correlation of second harmonic frequencies was good, but calculated amplitudes were much higher than observed amplitudes, Figure 70.

6.3 DISCUSSION

The verification tests show that the HSFR modeling program produces viable, satisfactory predictions of hydraulic resonances for 8000 psi systems. The first harmonic test data showed good correlation with the predicted resonant frequencies and peak pressures. No major resonant conditions were predicted or measured especially at the pump operating speed of 5900 RPM. While the second harmonic resonant frequency predictions correlated well with the measured data, the measured amplitudes were considerably less than the peak amplitudes predicted by the model. The analytical model was reviewed to determine an explanation; however, nothing specific was uncovered and the problem was not pursued. Since the higher harmonic resonant amplitudes in general fall off well below those of the fundamental frequencies, and since the model predictions are conservatively high, the problem of amplitude matching at the higher harmonics is considered to be of minor significance.

The testing disclosed that the system resonances are sensitive to fluid temperature. The experimentor must be careful to insure that the fluid at the test locations being investigated is at the precise temperature initialized in the analytical model. Under low flow conditions, a significant temperature differential can exist between the pump outlet and an actuator located at the extreme end of the system. Therefore, the actuators should be exercised until a uniform fluid temperature is obtained which should provide better correlation between the calculated and measured data.

The verification tests show that the HSFR program is a sufficiently reliable analytical tool to permit its application on the full scale LHS simulator in Phase II. While no problem resonant conditions were evident during the verification tests, the predictive capabilities of the program can be used with confidence to avoid and/or correct potential problem areas related to pump induced resonances on the full scale simulator.

The HSFR program in conjunction with the HYTRAN transient analysis and the HYTTHA thermal analysis programs will be evaluated on the LHS simulator during Phase II. The objectives of this effort will be to (1) evaluate the predictive capabilities of the three programs under controlled laboratory conditions, and (2) to identify and correct, within the scope of the program, problem areas in the analytical programs uncovered during testing.

6.4 AIR FORCE DATA

A group of engineers from the Air Force Propulsion Laboratory at Wright Patterson Air Force base, Dayton, Ohio, visited NAAD in October 1980. The purpose of the visit was to observe the compatibility test setup in operation and to take spectrum analysis data using their test equipment. The group was headed by Mr. E. Binns, Systems Chief, and Mr. P. Linquist, Project Engineer. Equipment brought to NAAD were:

- Spectrum Analyzer
- X-Y Plotter
- Piezo-Electric Clamp-On Pressure Transducer

Spectrum scans were run with the transducer clamped at several locations in FC-1 and FC-2. The scans covered increasing pump speeds from 2000 to 6000 rpm, and decreasing speeds from 6000 to 2000 rpm. The data were stored in the spectrum analyzer during the scans, then retrieved and displayed by the X-Y plotter after system shut-down. Three data plots are presented in Appendix C. The data confirmed that the LHS pressure ripple spectrum was relatively quiet. Peak pressures were less than the maximum allowable 200 psi (single amplitude). No major hydraulic resonance was observed over a pump speed range of 2000 to 6000 rpm.

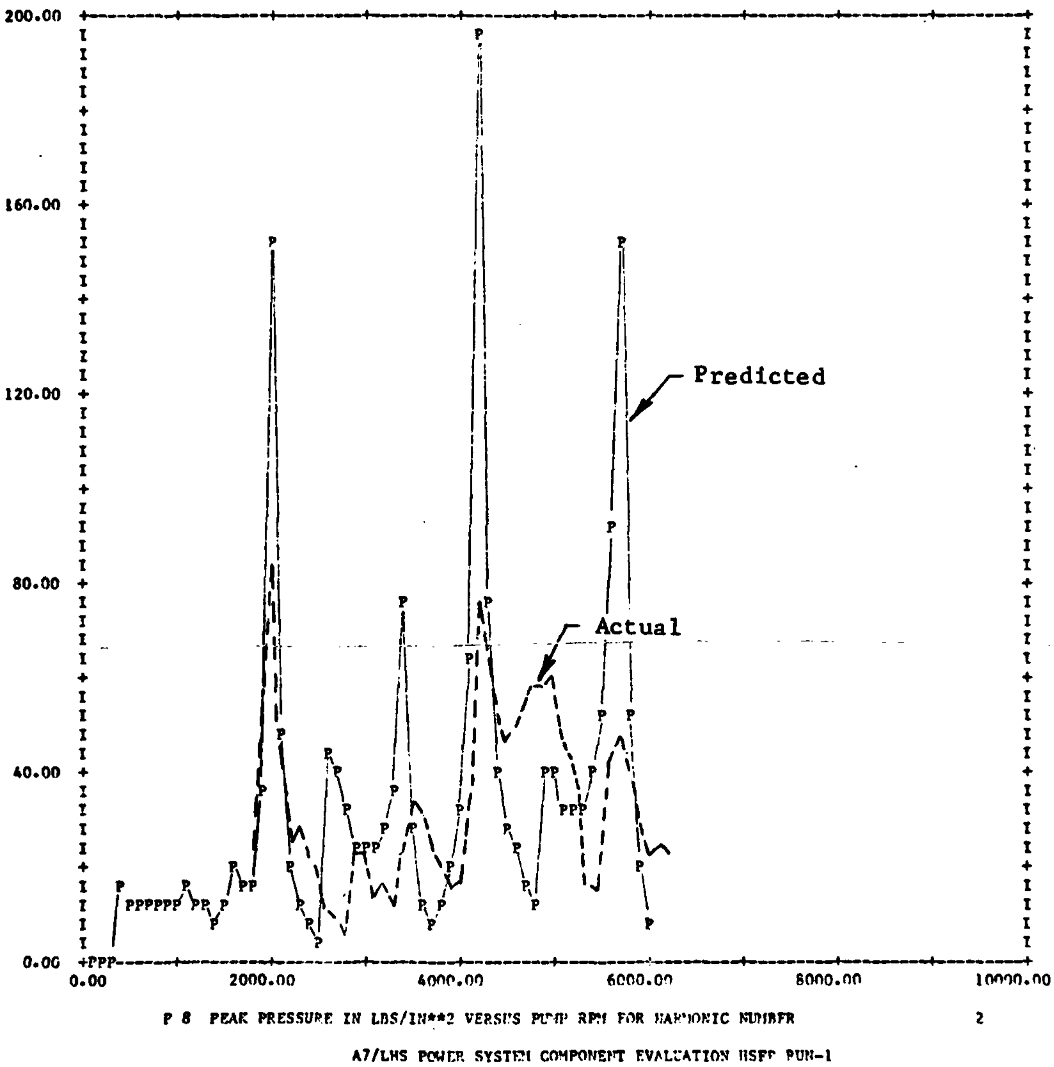


FIGURE 68. Peak pressure at P8, 2nd harmonic

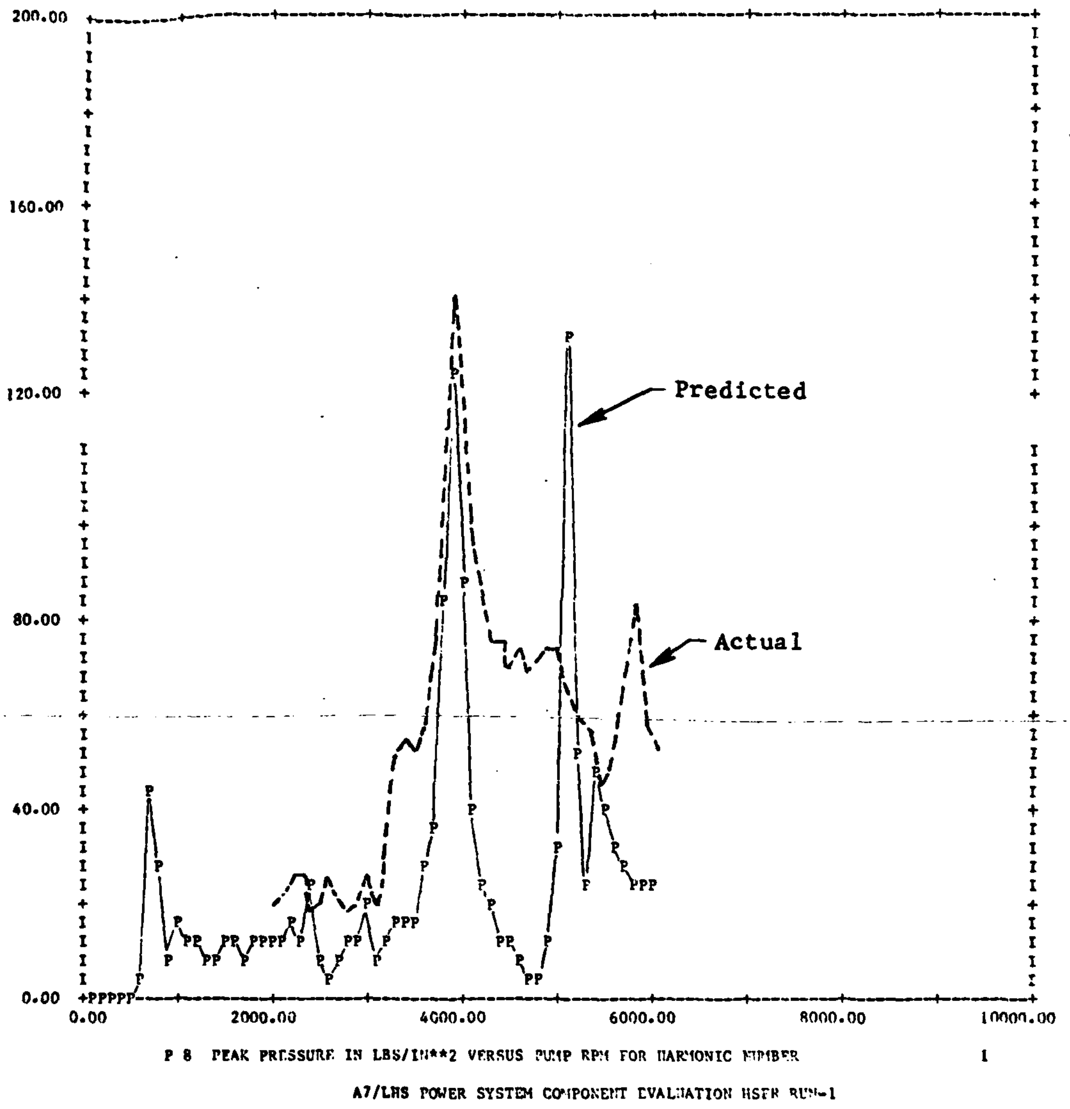


FIGURE 69. Peak pressure at P8, 1st harmonic, +200°F

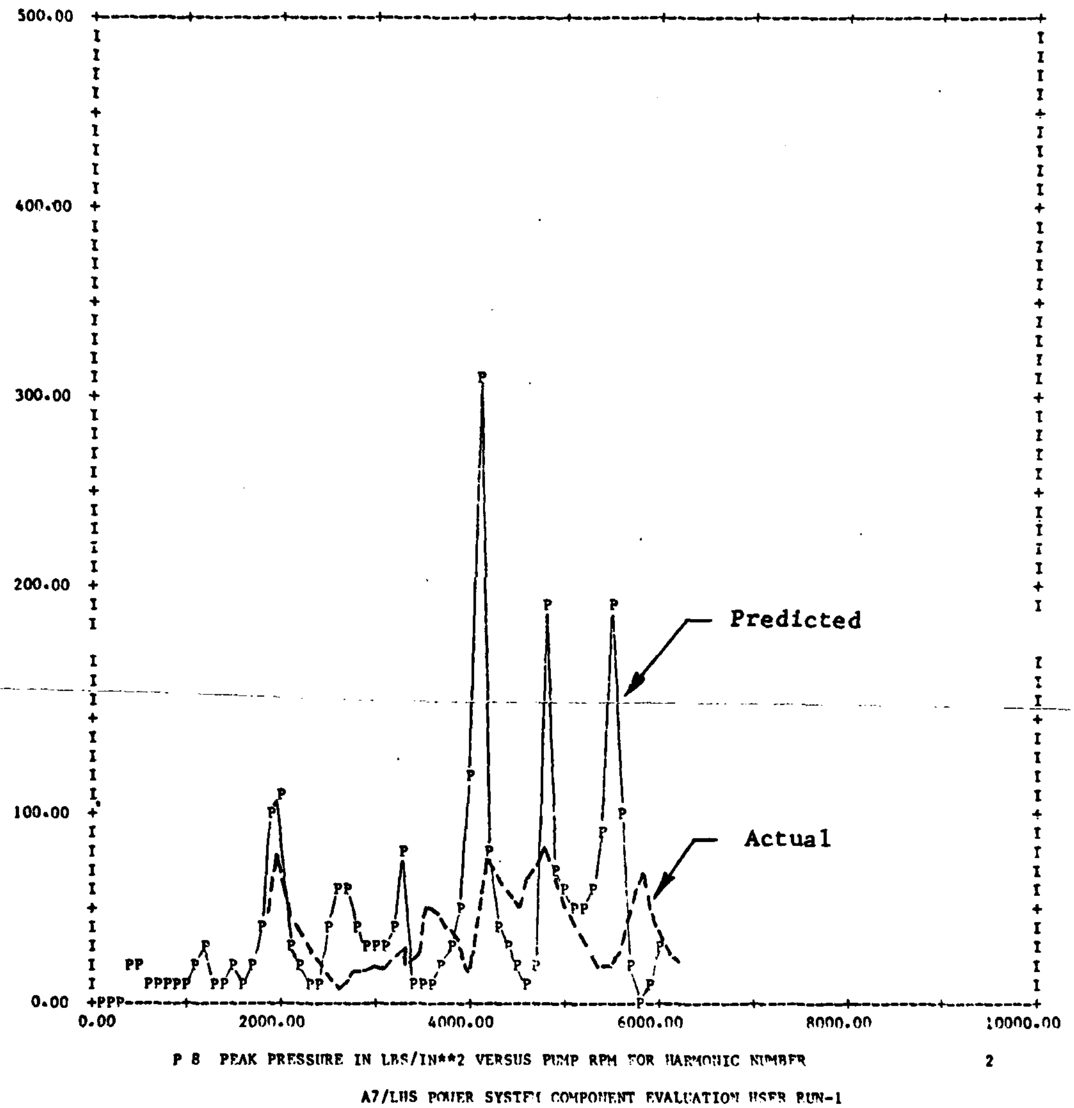


FIGURE 70. Peak pressure at P8, 2nd harmonic, +200°F

7.0 WEIGHT AND SPACE ANALYSIS

7.1 INTRODUCTION

The basic purpose of LHS technology is to reduce the weight of the installed hydraulic system. In addition, reduction in space occupied by smaller LHS components permits more compact installations, and in some cases, makes possible design approaches not practical with larger, lower pressure components. A major objective of the LHS program is to verify the projected 30% weight and 40% space savings achieved by progressing to an 8000 psi operating pressure level.

7.2 APPROACH

7.2.1 General Guidelines

Since the A-7E 8000 psi system configuration differs somewhat from the existing A-7E 3000 psi system arrangement, the A-7E data were modified to reflect the same configuration as the LHS system. A discussion of the A-7E 3000 psi and A-7E LHS configurations is given in section 2.0. The emergency power package (ram air turbine) was not included in the analysis since it operated at 3000 psi in FC-2 and its configuration was unchanged.

The following terminology will be used to clarify identification of the systems involved:

EXISTING system	The existing system or portion of a system configured in A-7E Aircraft BuNo 156801 and subsequents (A/C No. 157 and subs).
LHS system	The 8000 psi system or a portion of the system as depicted in Figure 3.
EQUIVALENT 3000 psi system	The existing system with changes incorporated to make it functionally identical to the LHS system.

The analysis compares the weight and space values of the LHS system with the EQUIVALENT 3000 psi system. The data were tabulated in two forms. One was a listing by subsystem: power generation, distribution, and actuation. The second was a tabulation by major elements: tubing, actuators, fluid, pumps, reservoirs, etc.

The analysis involved assessment of each component and line on a part-for-part basis using actual weights and calculated volumes for both the 3000 psi and 8000 psi components. Line lengths were obtained from existing production drawings. Average fitting weights per line were established for each type fitting, line size, and material. Actual 3000 psi actuator weights were used where applicable. When actuators with steel barrels were required, the weight and volume of an equivalent 3000 psi steel barrel actuator was used.

Guidelines followed in the analysis are summarized below:

- The system arrangement for both the LHS and EQUIVALENT 3000 psi systems is depicted in Figure 3.
- Any changes in capacity resulting from the addition/deletion of a subsystem during the rearrangement of the existing system was accounted for in line/component size.
- Where feasible, existing line routing was followed. When not feasible, the new routing used by the LHS and EQUIVALENT 3000 psi systems were assumed to be identical. The 3000 psi system tubing material and fitting style were assumed to be the same as that used in the old routing.
- Design approaches made possible by utilizing LHS were incorporated, where applicable, such as replacing line extension units and swivels with small coiled tubing.
- The LHS pressure and return lines were 3 Al-2.5V cold worked, stress relieved titanium tubing with the following design criteria:

  Pressure lines   24,000 psi burst pressure @ +275°F

  Return lines   12,000 psi burst pressure @ +275°F

- Line weights were categorized as follows:

  A line carrying fluid to or from more than one subsystem was considered to be in the "Distribution System".

  Lines carrying fluid to or from only one subsystem were assigned to that subsystem.

7.2.2 Tubing and Fittings

EQUIVALENT 3000 psi System - Each line assembly drawing in the 3000 psi FC-1 and FC-2 systems was reviewed to determine line size, material, and length, and fitting style and material. The line length thus determined was used in the 8000 psi analysis. Each 3000 psi line was tabulated and adjusted in size, if necessary, due to changes in flow resulting from systems rearrangement. Average fitting weights were determined for each style (MS or Aeroquip Braze), material (aluminum or steel), and size.

LHS System - The weight of each line was determined using actual line lengths or estimated line lengths where new routings were made. Average fitting weight per line was calculated using weights of the Deutsch Permaswage permanent fittings and Deutsch and Resistoflex "Dynatube" separable fittings.

7.2.3 Configuration Adjustments

Additional weight savings were achieved by incorporating the following adjustments:

- Use castings/forgings instead of "hog-outs"
- Use shrink-fit control valves on actuators instead of LHS valves made to fit standard size A-7 valve housings
- Run LHS pump at higher operating speed than is possible with existing A-7 gear box.
- Use LHS reservoir with more efficient design
- Use UHT actuator with the barrel diameter reduced one O-ring size

The above adjustments were included in both the EQUIVALENT 3000 psi and LHS system weight calculations. The adjustments were not included in the volume calculations because of their small effect. The reservoir, UHT actuator, and control valve changes are planned to be incorporated in the LHS aircraft system; the use of castings/forgings and change in pump speed are not planned for obvious economic and scheduling reasons.

7.3 RESULTS

Detail weight and space determinations are presented in Appendix C. Weight and space savings summaries are given on Tables 23 and 24. Weight savings achieved were:

Total weight of EQUIVALENT 3000 psi system	644.4 lb
Total weight of LHS system	449.7 lb
Weight reduction	194.7 lb
Weight savings	30.2%

Space savings achieved were:

Total volume of EQUIVALENT 3000 psi system	8173 in^3
Total volume of LHS system	5207 in^3
Volume reduction	2966 in^3
Space savings	36.3%

Table 23. Weight Savings Summary

	EQUIVALENT 3000 psi System	Percent of Sys. Weight	LHS System	Percent Red. in Comp.Wt.	Percent Red. in Sys.Wt.
Actuators	303.9	47.2	257.6	-15.2	-7.2
Pumps	26.2	4.1	22.8	-13.0	-0.6
Reservoirs	43.3	6.7	36.9	-14.8	-1.0
Tubing	75.9	11.8	31.4	-58.6	-6.9
Fittings	36.9	5.7	11.2	-69.6	-4.0
Fluid	76.0	11.8	38.9	-48.8	-5.7
Misc.	82.2	12.7	50.9	-38.1	-4.8
	644.4 lb	100%	449.7 lb		-30.2%

Table 24. Space Savings Summary

	EQUIVALENT 3000 psi System	Percent of Sys. Volume	LHS System	Percent Red. in Comp.Vol.	Percent Red. in Sys.Vol.
Actuators	3605	44.1	2304	-36.1	-16.1
Pumps	342	4.2	236	-31.0	-1.3
Reservoirs	1634	20.0	1187	-27.4	-5.5
Tubing	1243	15.2	596	-52.0	-7.9
Fittings	319	3.9	145	-54.5	-2.1
Misc.	1030	12.6	739	-28.2	-3.4
	8173 in^3	100 %	5207 in^3		-36.3%

The 30% weight savings goal was reached; the 40% space savings goal was nearly reached. Weight values are easily obtained using scales. Volume determinations are more difficult, and if calculated, require many approximations. The most accurate and practical method to determine component volume is water displacement; this was not attempted. More accurate and complete volume figures would increase space savings from the reported 36.3% to a value very close to the 40% goal.

8.0 R&M ASSESSMENT

8.1 INTRODUCTION

The purpose of the LHS technology development program is to establish the practicality of using an 8000 psi operating pressure to attain smaller and lighter weight hydraulic systems for future aircraft. Reliability and Maintainability (R&M) considerations are a part of this program, the objectives of which are to assess the potential gains high presure technology may have for R&M, and to identify and resolve (or recommend programs to resolve) R&M improvement opportunities in hydraulic systems or components.

8.2 R&M MODELS

The LHS as designed for this development is configured for an A-7 airplane which is to be used as a flight test vehicle for LHS in later phases of the program. The baseline for comparison of the LHS R&M has therefore been selected as the current A-7E hydraulic system. The development system will be comprised of components necessary for providing hydraulic power to the flight control system on A-7E aircraft. These components constitute those hydraulic elements of Work Unit Code (WUC) 14 and the FC-1 and FC-2 power systems of WUC 45. The Mean-Flight-Hours-Between-Failure (MFHBF) and the Maintenance-Man-Hours per Flight Hour (MMH/FH) models constructed for this program are structured from a listing of components for the LHS designed for this program. The MFHBF and the MMH/FH models are contained in Appendices D and E, respectively, of this Phase I program report.

The item numbers listed for each component identified on the model format correspond to the items as identified on the LHS schematic drawing 8696-580001, Figure 5. The format provides for listing the MFHBF/MMH/FH for both the 8000 psi components and equivalent 3000 psi components. This allows for a direct comparison of R&M between components of the current and high pressure systems. A column for Remarks/Rationale provides for a brief description of the basis upon which the 8000 psi component was predicted relative to the current experience.

8.3 BASELINE DATA SOURCES

The MFHBF used as a baseline for components of the 3000 psi system were established from a three year/353,446 flight hours sample of Navy 3M data for the A-7E airplane. This data was compiled, analyzed, and summarized by the Vought Corporation as a part of the A-7E program, and provided for use in the LHS program as a baseline set of typical current aircraft hydraulic reliability data. Failure criteria was established from the reported malfunction codes in the 3M data. Specific codes were judged as not being failures related to a deficiency in the given component, and were therefore excluded in calculating the MFHBF. The censorship criteria used is presented in Table 25. These same rules applied to the prediction of 8000 psi components.

Table 25. Censorship Criteria for Navy 3M Data

The following data codes were censored to obtain equipment level failures:

1. Burned out light bulbs or fuses
2. Improper handling
3. Missing parts
4. Loose or damaged bolts, nuts, or other common hardware
5. Broken, faulty, or missing safety wire or key
6. Cut
7. Deteriorated
8. On aircraft adjustment or alignment
9. Launch damage
10. Improper or faulty maintenance
11. Foreign object damage
12. Bird strike damage
13. FOD--self induced by ingestion of aircraft parts
14. Non-metallic contamination or dirty (except for hydraulic pump)
15. Lack of, or improper, lubrication
16. Nicked or chipped
17. Failed or replaced due to associated equipment
18. Air in system
19. Corroded (on aircraft maintenance only)
20. Faulty tape--program or checkout
21. Loose (on aircraft maintenance only)
22. Battle damage
23. Obsolete/surplus
24. Transportation damage
25. Weather damage
26. Burned or overheated (on hydraulic pumps only)
27. Accidental or inadvertent operation
28. Metal in oil strainer
29. Failure discovered upon removal from supply
30. System level work unit codes (zero in fifth digit; i.e., 14750)
31. Corrosion control
32. Repair and/or replacement of attaching units, seals, gaskets, packing, electrical connections, wiring, circuits, tubing, hose, connectors, fittings, etc., that are not an integral part of work unit coded items or components as purchased from the manufacturer and held in the supply system in an RFI status

The MMH/FH 3000 psi baseline data was extracted from a 132,420 flight hours sample of A-7E 3M data. This data was machine processed by the Vought Corporation, summarizing MMH/FH for each WUC.

8.4 PREDICTIONS

The limited test information available during this Phase I program hindered an in-depth analysis and prediction of reliability. All major components were designed and selected components fabricated for this program phase. The pump prediction presented was projected from an estimate made by Sperry-Vickers based on a failure-modes-and-effects-analysis (FMEA). The actuators (with exception of the rudder actuator), coiled tubing, and reservoir predictions were prepared by the Vought Corporation by a direct comparison to the design of the 3000 psi components. The number of leak paths was the basis of comparison for the projections; the improved seals and smaller piston size factors were assumed to be offset by the higher pressures for this initial prediction. The predictions prepared by Vought were adjusted by Rockwell to reflect slight differences between the data bases used in order to maintain consistency.

Reliability of minor LHS components was subjectively predicted by discussions between hydraulic system/laboratory engineers and the reliability engineer. When specific reasons could not be envisioned to substantiate either an improvement or degradation in failure rate, the estimate remained unchanged from the A-7E baseline. Where known factors influence the failure rate, these factors/rationale are briefly noted in the appropriate column of the prediction format.

Maintainability predictions for the LHS were changed proportionately to the reliability estimates. A reduced failure frequency was assumed to reduce the MMH/FH by the same proportion. Most maintenance time is a result of installation factors, and this program is not intended to improve on the basic maintenance characteristics that are already inherent in the A-7 airplane. At this phase in the program, when the hardware is limited and not installed in an aircraft, the frequency of maintenance is the most influential factor defining differences between 8000 psi and 3000 psi systems. The predictions for both R&M are included in the R&M models of Appendices D and E, respectively.

8.5 FAILURE REPORTS AND ANALYSIS

Laboratory logs of all operations and failures during the Phase I testing were maintained on an hourly/daily basis. A summary of the reliability and maintainability significant actions relative to the LHS components is summarized in Table 26. Also presented in the table is a brief summary of the actions/initial analysis made of the failure. Appendix F includes analyses from Vought, Sperry-Vickers, and Bendix on failures experienced with the actuators, pumps, and solenoid valves, respectively.

TABLE 26. Failure Reports And Analysis

COMPONENT	PART NUMBER	TEST	TIME OF FAILURE	FAILURE DESCRIPTION/LOCATION	PROBABLE CAUSE OF FAILURE	PRELIMINARY RECOMMENDATIONS
RUDDER ACTUATOR CONTROL VALVE UHT ACTUATOR CONTROL VALVE	83-00213 83-00213-111	ACCEPTANCE	-- SEE SECT. 5.3.6.2	-SPOOL STICKS WHEN ALLOWED TO REMAIN AT ONE POSITION FOR MORE THAN APPROX. 10 SEC. -NULL LEAKAGE NEAR ZERO WHEN VALVE STICKS -VALVE PERFORMS SATISFACTORILY AS LONG AS SPOOL IS MOVING	-INSUFFICIENT DIAMETRAL CLEARANCE BETWEEN SPOOL AND SLEEVE. OPERATION AT 8000 PSI CAUSED SLEEVE TO DEFLECT INWARD AND CLAMP 3-LAND SPOOL. CHECKOUT TESTS AT 3000 PSI DID NOT DEFLECT SLEEVE SUFFICIENTLY TO CLAMP SPOOL AND SHUT OFF NULL FLOW.	1. INCREASE DIAMETRAL CLEARANCE BETWEEN SPOOL AND SLEEVE
PUMP	PV3-047-2 S/N 346581 S/N 348168	ACCEPTANCE	-- SEE SECT. 5.3.6.1	1. EXCESSIVE PRESSURE DROOP 2. EXCESSIVE HEAT REJECTION 3. COMPENSATOR SETTING AFFECTED BY OPERATING TEMPERATURE	1. NORMAL DEVELOPMENT PROBLEM 2. DISTORTION IN VALVE BLOCK, EXCESSIVE PISTON/BORE CLEARANCE 3. NORMAL DEVELOPMENT PROBLEM	1. REVISE PUMP TIMING, INCREASE YOKE MOMENT 2. REPLACE ALUMINUM VALVE BLOCK WITH STEEL, REQUIRE CLOSER CONTROL ON PISTON/BORE DIMENSIONS 3. INCREASE CONTROL PISTON DIA., PUT ORIFICE IN CONTROL PRESSURE CIRCUIT
TEE	DNR10023-080308	PROOF	-- SEE SECT. 5.3.6.4	- -8 SIZE TUBE BLEW OUT OF ONE LEG OF TEE AT 15,500 PSI (FC-1 SYSTEM)	- 21-6-9 CRES TUBING HAS TENSILE STRENGTH OF 155,000 PSI - LHS TUBING THUS HARDER THAN CONVENTIONAL TUBING	1. PERFORM 3 SWAGING OPERATIONS 120° APART INSTEAD OF ONE SWAGE NORMALLY RECOMMENDED
ADAPTER FITTING	R44182T-08	COMPATIBILITY	39.3 HRS. SEE TABLE 19	-SPRAY LEAK FROM BOSS SEAL ON INLET PORT OF FC-1 PRESSURE FILTER	-O-RING FAILED DUE TO ROUGH SURFACE ON FITTING WHERE O-RING SEALED	1. ASSURE QUALITY CONTROL OF DRY FILM COATING ON FITTING
O-RING	MS28778-04	COMPATIBILITY	45.7 HRS. SEE TABLE 19	-LOW PRESSURE LEAK OCCURRED OVER WEEKEND. RESERVOIR BOOTSTRAP PRESSURE CAUSED FLUID LOSS -LEAK OCCURRED AT MS BULKHEAD FITTING NEAR P5 PRESSURE TRANSDUCER IN FC-2	-O-RING HAD PERMANENT SET -O-RING MAY HAVE HAD OUT-OF-DATE CURE DATE	1. ASSURE THAT O-RING HAS PROPER CURE DATE
PUMP	PV3-047-2 S/N 346581	COMPATIBILITY	50 HRS. SEE SECT. 5.3.6.1	-EXCESSIVE CASE FLOW DEVELOPED DURING 50 HR. PERFORMANCE CHECK (FC-1 PUMP)	-PART OF ONE PISTON SHOE MISSING DUE TO BRAZING VOIDS	1. ASSURE QUALITY CONTROL OF BRAZING PROCESS

TABLE 26. Failure Reports And Analysis (Continued)

COMPONENT	PART NUMBER	TEST	TIME OF FAILURE	FAILURE DESCRIPTION/LOCATION	PROBABLE CAUSE OF FAILURE	PRELIMINARY RECOMMENDATIONS
PUMP	PV3-047-2 S/N 346581	COMPATI-BILITY	56.2 HRS. SEE SECT. 5.3.6.1	-PIN HOLE LEAK DEVELOPED IN VALVE BLOCK OF FC-1 PUMP	-FATIGUE STRENGTH OF MATERIAL TOO LOW	1. REPLACE ALUMINUM VALVE BLOCK WITH STEEL VALVE BLOCK
PUMP	PV3-047-2 S/N 348168	COMPATI-BILITY	102.6 HRS. SEE SECT. 5.3.6.1	-EXTERNAL LEAK DEVELOPED IN JOINT BETWEEN VALVE BLOCK AND HOUSING OF FC-2 PUMP	-EROSION PITTING OF O-RING GLAND IN ALUMINUM VALVE BLOCK CAUSED O-RING TO FAIL. -VALVE BLOCK MATERIAL TOO SOFT.	1. REPLACE ALUMINUM VALVE BLOCK WITH STEEL VALVE BLOCK
PUMP	PV3-047-2 S/N 348168	--	FAILURE NOTED DURING PUMP DIS-ASSEMBLY AT 102.6 HRS.	-SPALLING ON HIGH PRESSURE PINTLE BEARING INNER RACE (FC-2 PUMP)	-DESIGN LOAD TOO LOW	1. USE HEAVIER DUTY BEARING
4-WAY SOLENOID VALVE	3321472	COMPATI-BILITY	119.0 HRS. (19 HRS ON VALVE) SEE SECT. 5.3.6.8	-VALVE STOPPED OPERATING AT 1043 CYCLES. -VALVE IN SPEED BRAKE SECTION IN FC-1 SYSTEM	-SOFT SOLENOID SPACER PIN CAUSED LOSS OF SOLENOID STROKE. -DAMAGED PILOT PIN - INSUFFICIENT MATERIAL TO REACT LOAD	1. ASSURE PROPER HEAT TREAT OF SPACER PIN 2. REDESIGN PILOT PIN CONFIGURATION
AFCS ACTUATOR	83-00231	COMPATI-BILITY	128.9 HRS. SEE SECT. 5.3.6.2	-CYLINDER #2 PISTON OPERATION BECAME ROUGH. -ACTUATOR IN FC-2 SYSTEM.	-INTERNAL BINDING SUSPECTED. -CAUSE OF ROUGH OPERATION TO BE DETERMINED WHEN ACTUATOR IS DISASSEMBLED.	
FLUID	MIL-H-83282	COMPATI-BILITY	-- SEE SECT. 5.3.6.3	PUMP CASE DRAIN FILTERS IN FC-1 AND FC-2 SYSTEMS BECAME LOADED WITH BLACK PARTICLES, NECESSITATING FREQUENT ELEMENT CHANGES. BLACK PARTICLES ALSO NOTED IN FC-1 AND FC-2 PRESSURE AND RETURN FILTERS, HOWERVER THESE FILTERS HAD A LARGER CAPACITY AND WERE NOT CHANGED DURING THE 150 HR. TEST. PARTICLE SIZE ESTIMATED TO BE LESS THAN ONE MICRON.	-CAUSE AND SOURCE OF THE BLACK PARTICLES NOT ESTABLISHED. -PRIOR ANALYSIS DISCLOSED THE PARTICLES ARE 99% CARBON, REFERENCE 10.	1. THE FOLLOWING OBSERVA-TIONS SHOULD BE NOTED: -HUNDREDS OF HOURS OF TESTING HAVE BEEN ACCUMU-LATED AT NADC USING MIL-H-83282 AT 8000 PSI. NO BLACK PARTICLES HAVE BEEN OBSERVED. -A 400 HR. SEAL TEST WAS CONDUCTED BY VOUGHT USING MIL-H-83282 AT 8000 PSI. NO BLACK PARTICLES WERE OBSERVED. 2. INVESTIGATION IN THIS AREA IS WARRANTED

TABLE 26. Failure Reports And Analysis (Continued)

COMPONENT	PART NUMBER	TEST	TIME OF FAILURE	FAILURE DESCRIPTION/LOCATION	PROBABLE CAUSE OF FAILURE	PRELIMINARY RECOMMENDATIONS
3-WAY SOLENOID VALVE	3321473	PRESSURE IMPULSE	NOT KNOWN SEE SECT. 5.4	-VALVE INOPERATIVE -FAILURE NOT DETECTED UNTIL AFTER COMPLETION OF 40,000 CYCLE TEST	-SOFT SOLENOID SPACER PIN CAUSED LOSS OF SOLENOID STROKE. -DAMAGED PILOT PIN - INSUFFICIENT MATERIAL TO REACT LOAD.	1. ASSURE PROPER HEAT TREAT OF SPACER PIN 2. REDESIGN PILOT PIN CONFIGURATION
QUICK DISCONNECT (UNCOUPLED, WITH DUST COVER)	AE80943H	PRESSURE IMPULSE	NOT KNOWN SEE SECT. 5.4	-WEB AREAS BETWEEN PORTING HOLES IN STEEL VALVE FAILED. -FAILURE NOT DETECTED UNTIL AFTER COMPLETION OF 40,000 CYCLE TEST.	-INSUFFICIENT MATERIAL IN WEB AREAS BETWEEN PORTING HOLES.	1. SPECIFICATION LHS-8828 HAS NO PRESSURE IMPULSE TEST REQUIREMENTS FOR UNCOUPLED DISCONNECTS 2. UPDATE LHS-8828 SPECIFICATION AND INVOKE COMPLIANCE WITH REVISED SPECIFICATION.
O-RING	MS28775-015	COMPONENT ENDURANCE	800 CYCLES SEE TABLE 21	-FACE SEAL O-RING EXTRUDED OUT -SEAL ON AIR FILL VALVE FOR LHS ACCUMULATOR	-AIR FILL VALVE LOOSE IN BOSS PORT ON MANIFOLD	1. LOCKWIRE AIR FILL VALVE TO MANIFOLD 2. AIR FILL VALVE USED WAS MS28889 AND RATED FOR 5000 PSI SERVICE 3. PROCURE LHS AIR FILL VALVE WITH BOSS TYPE STATIC SEAL
CHECK VALVE	95202-5	COMPONENT ENDURANCE	826 CYCLES SEE TABLE 21	-DIAMETRAL SEAL EXTRUDED OUT -VALVE USED PREVIOUSLY IN 150 HR. COMPATIBILITY TEST IN FC-2 SYSTEM	-IMPROPER GLAND DESIGN -VALVE HALVES WORKED LOOSE	1. INCREASE OVERLAP AT SEAL DIAMETRAL CLEARANCE 2. INCREASE ASSEMBLY TORQUE 3. INSTALL LOCKWIRE ON VALVE
CHECK VALVE	95201-5	COMPONENT ENDURANCE	NOT KNOWN SEE TABLE 21	-POPPET FAILED IN WEB AREAS AROUND PORTING HOLES -FAILURE NOT DETECTED UNTIL AFTER COMPLETION OF ENDURANCE TEST -VALVE USED PREVIOUSLY IN 150 HR. COMPATIBILITY TEST IN FC-1 SYSTEM	-INSUFFICIENT MATERIAL IN WEB AREAS AROUND PORTING HOLES	1. INCREASE POPPET WEB AREAS

TABLE 26. Failure Reports And Analysis (Continued)

COMPONENT	PART NUMBER	TEST	TIME OF FAILURE	FAILURE DESCRIPTION/LOCATION	PROBABLE CAUSE OF FAILURE	PRELIMINARY RECOMMENDATIONS
4-WAY SOLENOID VALVE (RE-WORKED)	3321472	COMPONENT ENDURANCE	3000 CYCLES SEE SECT. 5.5	-VALVE BEGAN TO MALFUNCTION AT 2530 CYCLES AND STOPPED OPERATING AT 3000 CYCLES. -VALVE OPERATED PREVIOUSLY FOR 1518 CYCLES IN COMPATIBILITY TEST.	-RETURN BALL IN PILOT VALVE WEDGED IN CROSS DRILLED FLOW PASSAGE, AND JAMMED WHEN SOLENOID WAS ENERGIZED. -HARDENED SPACER PIN AND PILOT PIN DAMAGED DUE TO ECCENTRIC LOADING ON DISLODGED BALL.	1. RELOCATE CROSS DRILLED FLOW PASSAGE
LIP SEAL TYPE SEPARABLE FITTING	DEUTSCH & RESISTOFLEX	COMPATIBILITY, PRESSURE IMPULSE	-- SEE SECT. 5.3.6.4 & 5.4.2	-SLIGHT SEEPAGE FROM SEPARABLE JOINTS. -RATE ESTIMATED AT 1 DROP PER 10 HOURS OF TEST TIME. -APPROX. 30% OF JOINTS IN A TEST SYSTEM SEEPED. REMAINING 70% DID NOT SEEP.	1. MINUTE IMPERFECTIONS ON LIP SEAL SURFACES MADE DURING MANUFACTURE. 2. SMALL SCRATCHES MADE ON LIP SEAL SURFACES DURING PLUMBING FABRICATION.	1. ASSURE CAREFUL MANUFACTURING AND HANDLING PROCEDURES. 2. ASSURE CAREFUL FABRICATION AND HANDLING PROCEDURES.

The pumps have been the pacing components in the test program, and these problems have been expanded upon and briefed in the quarterly reports and coordination meetings. The resulting program stretch-out, and re-ordering of events between the Phase I and Phase II programs have established that more detailed failure analysis of the Phase I test program will be more efficiently combined with the FMEA studies of Phase II. Thus, the impact of the failures on the system R&M predictions will be assessed relative to the final FMEA. A preliminary FMEA has been completed, and review is now being initiated by Rockwell engineers in conjunction with the Phase I test results/failures just completed.

Significant to R&M concerns with the LHS is the frequency of filter element changes. Related to this is the frequent patch tests conducted during the program in which a black substance was collected from the fluid. This has been noted in previous high pressure hydraulic programs, but the cause is speculative. Although this has occurred only in the Rockwell conducted tests, it is recommended that a controlled test/study effort be directed to determine the exact cause.

8.6 CONCLUSIONS/RECOMMENDATIONS

The A-7 FMEA for the hydraulics system was reviewed with the reported maintenance and failure data from A-7E operations to establish the more significant R&M factors. The failure modes and the malfunction codes from the 3M data verifies that leaking is by far the most significant factor in the cause of repair actions in hydraulic systems. An analysis of the baseline data compiled for the 3000 psi system revealed that 10 components, or component types, contribute over 75% of the total failure rate. These items and their respective contributions are listed in Table 27.

TABLE 27. Failure Rate Contributions to Current Hydraulic Systems

Item	% Contribution
Extension Units	23
Disconnects	11.4
Filters	10.6
Tubing/Fittings	6.5
AFCS Actuators	6.5
Aileron Actuators	5.6
Swivel Joints	4.5
Pumps	4.0
Pressure Transmitter	2.7
UHT Actuator	2.6

The potential leaking problem with high pressures was addressed early in the program. As a part of the initial planning, a seal improvement and test program was structured to establish the optimum seals to be used in high pressure components. The improved seals resulting from these tests have been used in the design of the actuators which were built and tested during this program phase.

The extension units, recognized as the highest contributing item to system failure rate, were able to be eliminated by the use of coiled tubing. Use of the coiled tubing became possible directly as a result of the high pressure technology. This facilitated the use of smaller diameter tubing for the coils, which in turn, allowed for installation within the space restrictions in the A-7 airplane.

The recognition and actions taken during this program phase on the above potential problems have resulted in a projected 44% improvement in system MFHBF and a 16.7% improvement in system MMH/FH. These improvements are based on the actions taken for the development hardware, and which were identified in the rationale for the predictions. It is premature at this phase in the program to "identify further improvements which may be implemented for production; therefore, production improvements percentages have not been estimated at this time. The program goal of 15% improvement in system R&M for development hardware appears to have been exceeded based on the program efforts to date. The improvements achieved re-orders the failure rate contributors; the revised order being shown in Table 28.

TABLE 28. Failure Rate Contribution to 8000 psi Hydraulic System

Item	% Contribution
Quick Disconnects	16.5
Filter	15.3
AFCS Actuators	6.6
Aileron Actuators	5.9
Pump	5.3
Tubing and Fittings	4.7
Pressure Transmitter	3.9
UHT Actuator	3.8
Swivel Joints	3.4
Reservoir	3.3

Ordering the six highest maintenance rate items, Table 29, it is noted that five of the six are also among the top failure rate contributors.

TABLE 29. Maintenance Rate Contributions to 8000 psi Hydraulic System

Item	% Contribution
UHT Actuator	15
Restrictors	12.6
AFCS Actuators	10.2
Filters	9.3
Aileron Actuators	7.6
Pumps	5.8

AD-A097 505 ROCKWELL INTERNATIONAL COLUMBUS OH NORTH AMERICAN AI--ETC F/G 13/7
DESIGN, DEVELOPMENT, AND EVALUATION OF LIGHTWEIGHT HYDRAULIC SY--ETC(U)
JAN 81 J N DEMARCHI, R K HANING N62269-78-C-0363

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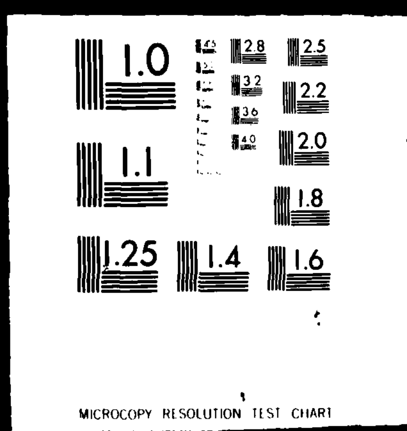


The significance of these tables is the appearance of items which may be considered minor system components. However, the quantity of these items used in the system results in R&M influence not otherwise considered as a potential problem. Quick disconnects, ten of which are used in the system, are using the same number of seals as their 3000 psi counterparts even though "leaking" has been identified as contributing to 89% of the failure rate. Six turns are required to release these devices, which is not considered to be "quick release". Filters unfortunately appear to have a high failure rate partially because the general definition of failure includes the modes of "clogged", "Metal in filter", "No-go indication", and "low output"; all of which are evidence of its doing its job. However, 78% of the failure modes on filters were attributed to "leaking", which is an apparent undesirable failure mode requiring attention.

9.0 GSE INTERFACE REQUIREMENTS

An analysis of hydraulic ground support equipment (GSE) requirements for aircraft with lightweight hydraulic systems disclosed that support equipment requirements are the same as current aircraft with an operating pressure of 3000 psi. Equipment required at the Organizational Level are a portable test stand, fluid servicing equipment, and a contamination analysis kit. At the Intermediate Level, a stationary test standard and a hose burst test stand are required. The fluid servicing equipment and the contamination analysis equipment will be essentially the same current equipment. Test stands will be the same except for operating pressure level.

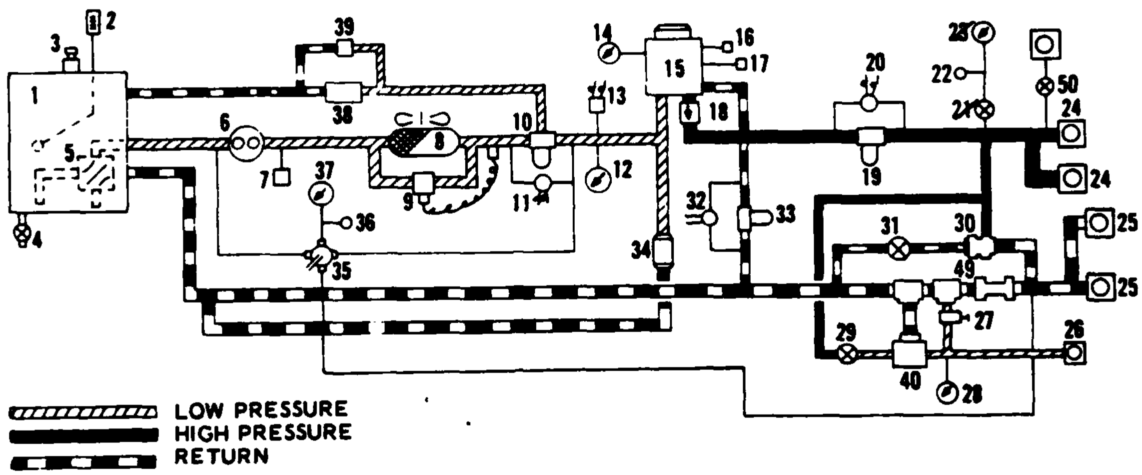
9.1 FOLLOW-ON PROGRAMS

For follow-on phases of the LHS advanced development program, the contractor intends to utilize existing equipment for servicing, fluid analysis, and hose burst tests. This is in accordance with a primary objective to provide the most cost effective options for the development phases of LHS. For test stands, a portable and a fixed unit are desirable for the full scale simulator test phase; however, in regards to cost effectiveness, it is possible to proceed without a fixed test stand during full scale simulator testing. A portable and a fixed unit is considered mandatory to support subsequent phases for aircraft hangar test, engine ground test, and flight test. Other GSE required to support aircraft systems other than the hydraulic system during hangar, ground, and flight test phases will be addressed under future follow-on efforts.

Cost for providing 8000 psi portable test stands for future follow-on phases can be minimized by modifying existing 3000 psi equipment such as the Models AHT-63/-64, into 8000 psi units. In these test stands, there are a total of approximately fifty (50) components. Of these, only twelve (12) are associated with the high pressure delivery subsystem of the unit. Modification of those units can be accomplished by replacing the eleven (11) 3000 psi components, as noted with asterisks on the system schematic, Figure 71, with 8000 psi components. The high pressure pump is the most complex and consequently the most expensive of the noted components.

Providing an 8000 psi pressure source can be accomplished by one of two methods; (1) utilizing an existing 8000 psi pump, development hardware, or industrial type, adapted to the test unit, or (2) using the existing 3000 psi pump to drive a 3000 psi to 8000 psi intensifier. The intensifier is essentially pump/motor technology; however, no known acceptable unit exists and therefore would require development of a new component. The intensifier approach is not considered a cost effective option and does not offer any schedule advantage, and therefore is not recommended.

It is recommended that a model AHT-63 test stand be made available for use in the LHS program.



1. Fluid Reservoir
2. Fluid Level Gage
3. Reservoir Fill and Vent
4. Reservoir Drain Valve
5. Reservoir Selector Valve
6. Boost Pump
7. Low Boost Shutdown
8. Oil Cooler
9. Oil Temperature Controller
10. Low Pressure Filter
11. Pressure Differential Switch
12. Fluid Temperature Gage
13. Thermoswitch
14. Pump Volume Pointer
*15. High Pressure Pump
16. Pump Volume Control
17. Pressure Compensator Control
*18. Check Valve
*19. High Pressure Filter
*20. Pressure Differential Switch
21. Gage Shutoff Valve
22. Gage Test Connection
*23. High Pressure Gage
*21. High Pressure Disconnect
25. Return Disconnect
26. Fill System Disconnect
27. Fill System Relief Valve
28. Fill System Pressure Gage
29. Fill System Shutoff
* 30. High Pressure Relief Valve
* 31. High Pressure Bypass
32. Pressure Differential Switch
33. Pump Case Filter
34. Pump Case Filter
35. Gage Selector Valve
36. Gage Test Connection
37. Compound Pressure Gage
38. Air Bleed Valve
39. Thermal Relief Valve
40. Pressure Reducing Valve
49. Return Back Pressure Relief
50. Fluid Sampling Valve

*51. Pressure Hose, A/C to GSE

***Components in high pressure delivery system.**

FIGURE 71. Typical 8000 psi portable test system

9.2 PRODUCTION GSE

The support requirements for future production aircraft with LHS will be the same as 3000 psi systems except the operating pressure of the portable and fixed test stands must be increased from 3000 to 8000 psi. No unique types of equipment need be developed. An informal survey of test stand component suppliers revealed that the hydraulic pump development suitable for production requirements would have the longest lead time of all the high pressure components.

10.0 CONCLUSIONS

Major advances toward achieving the goals of the LHS program were made in Phase I:

- Successful testing of four 8000 psi flight control actuators and one utility actuator
- Significant progress in developing a lightweight variable delivery 8000 psi pump
- Satisfactory operation of dual 8000 psi aircraft type hydraulic systems
- Completion of 150 hours of endurance test cycling on two 8000 psi hydraulic systems
- Completion of pressure impulse and endurance cycling of 8000 psi components
- Evaluation of servo valve erosion
- Verification of the predictive capability of a math model of the test system
- Projected 30.2% weight and 36.3% volume savings for lightweight hydraulic systems
- Prediction that the R&M goal of 15% reduction in MFHBF and MMH/FH for development hardware is realistic.

The principal achievement in Phase I was the successful operation of two 8000 psi hydraulic systems containing many of the components to be installed in the Phase II aircraft simulator. The integrated systems were stable, pressure fluctuations were low, and actuator operation was satisfactory. The 150 hour compatibility test provided further proof that 8000 psi hydraulic systems are practical and do not require state-of-the-art advances. Work accomplished in Phase I will provide a sound basis for successful implementation of the tasks planned in Phase II.

In view of the inability of the LHS pump to complete the 150 hour compatibility test, additional pump development effort is warranted.

11.0 RECOMMENDATIONS

Preparations for the construction of an A-7E full scale lightweight hydraulic system simulator were completed in Phase I. The tasks listed below are recommended to be performed in Phase II. Successful completion of these tasks will provide the knowledge and confidence necessary to assure a successful flight test program in Phase III.

Task I — Fabricate LHS Components (see Table 30)

- Major components
- Minor components
- Special components

Task II — Fabricate LHS Simulator

- Prepare detail drawings and fabricate mechanical control linkages and supports
- Fabricate simulator structure, Figure 27
- Fabricate load modules, Table 30
- Integrate modules into simulator and install mechanical control linkage system
- Fabricate FC-1 and FC-2 system plumbing; fabricate load and control system plumbing
- Prepare electrical control circuit drawings and install wiring
- Install simulator controls and instrumentation

Task III — Conduct Simulator Tests

- Proof pressure
- System integration
- Steady-state baseline
- Dynamic performance
- Math model verification
- 3000 psi/8000 psi system performance comparisons
- 300 hour mission profile/endurance test

Task IV	<u>Component Redesign/Retest</u>

- Make recommendations for modifications based on test experience and reliability analysis
- Estimate level of retesting required to validate the design changes

Task V	<u>Math Model Development/Verification</u>

- Hydraulic system frequency response
- Hydraulic transients and dynamics
- Hydraulic transient thermal analysis

Task VI	<u>System Weight and Space Analysis</u>

- Update Phase I analysis
- Include Phase II components
- Update projected weight and space savings

Task VII	<u>Specification Update</u>

- Revise LHS specifications, as necessary, based on Phases I and II test experience

Task VIII	<u>Reliability and Maintainability Assessment</u>

- Conduct FMEA
- Update MFHBF and MMH/FH
- Make design change recommendations, as necessary
- Prepare FMEA report
- Prepare Phase III R&M plan

Task IX	<u>GSE Requirements</u>

- Modify portable test stand M/N AHT-63 to operate at 8000 psi
- Evaluate performance of modified test stand

Task X	<u>LHS Pump</u>

- Perform additional development effort

TABLE 30. LHS Components To Be Fabricated In Phase II

Major Components	Quantity
Actuator, Spoiler	2
Actuator, Aileron	1
Actuator, Roll Feel	1
Actuator, AFCS	2
Actuator, UHT	1
Actuator, L.E. Flap	8
Pump	1
Servo Valve, AFCS	6
Electronics, AFCS	3
Minor Components	
Check Valves	13
Directional Flow Control Valves	
Solenoid, 2-way	1
Solenoid, 3-way	2
Solenoid, 4-way	1
Fittings, Permanent	200
Fittings, Separable	200
Fluid	100 gal.
Hose, Press.	4
Hose, Ret.	4
Quick Disconnect	2
Restrictor	9
Seals	400
*Swivel, Wing Fold	2
Swivel, Speed Brake	2
Tubing, Titanium	1200 ft.
Special Components	
Coiled Tubing	32
Manifold, Press.	1
Manifold, Ret.	1
Load Modules	
Spoiler	2
Aileron	1
UHT	1
L.E. Flap	2

*Requirements for a wing fold swivel are not firm at this time.

12.0 REFERENCES

REFERENCE NO.

1 D. Deamer, S. Brigham, Theoretical Study of Very High Pressure Fluid Power Systems, NA66H-822, North American Aviation, Inc., Columbus Division, Contract NOw65-0567-d, 15 October 1966, Unclassified. AD 803 870

2 J. Stauffer, Dynamic Response of Very High Pressure Fluid Power Systems, NR69H-65, North American Rockwell Corporation, Columbus Division, Contract N00019-68-C-0352, 16 April 1969, Unclassified. AD 854 142

3 J. Demarchi, Dynamic Response Test of Very High Pressure Fluid Power Systems, NR70H-533, North American Rockwell Corporation, Columbus Division, Contract N00156-70-C-1152, 9 December 1970, Unclassified. AD 891 214L

4 J.N. Demarchi and R.K. Haning, Application of Very High Pressure Hydraulic Systems to Aircraft, NR72H-20, Columbus Aircraft Division, North American Rockwell Corporation, Contract N62269-71-C-0147, March 1972, Unclassified. AD 907 304L

5 J.N. Demarchi and R.K. Haning, Lightweight Hydraulic System Development, NR73H-20, Columbus Aircraft Division, Rockwell International Corporation, Contracct N62269-72-C-0381, May 1973, Unclassified. AD 911 672L

6 J.N. Demarchi and R.K. Haning, Preparations for Lightweight Hydraulic System Hardware Endurance Testing, NR73H-191, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-73-C-0700, December 1973, Unclassified. AD B-001 857L

7 J.N. Demarchi and R.K. Haning, Lightweight Hydraulic System Hardware Endurance Test, NR75H-22, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-74-C-0511, March 1975, Unclassified. AD A-01? 244

8 J.N. Demarchi and R.K. Haning, Design and Test of an LHS Lateral Control System for a T-2C Airplane, NR76H-14, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-75-C-0422, May 1976, Unclassified. AD A-032 677

9 J.N. Demarchi and R.K. Haning, Flight Test of an 8000 psi Lightweight Hydraulic System, NR77H-21, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-76-C-0254, April 1977, Unclassified. AD A-039 717/4GA

10 J.N. Demarchi and R.K. Haning, Lightweight Hydraulic System Extended Endurance Test, NR78H-92, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-78-C-0005, September 1978, Unclassified. AD A062 749

11 Rockwell International Corporation Letter 79CL 1235, Submittal, Engineering Drawings and Design Layouts, North American Aircraft Division to Naval Air Development Center, dated 8 November 1979

12 Rockwell International Corporation Letter 80CL 973, Submittal, Lightweight Hydraulic System Advanced Development Program Specifications, North American Aircraft Division to Naval Air Development Center, dated 10 October 1980

13 NR73H-107, Control-by-Wire Actuator Model Development for AFCAS, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-73-C-0405, January 1974, Unclassified. AD 772 588

14 NR75H-1, Control-by-Wire Modular Actuator Tests (AFCAS), Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-73-C-0405, January 1975, Unclassified. AD A-006 371

15 NR78H-36, Flight Verification of the Advanced Flight Control Actuation System (AFCAS) in the T-2C Aircraft, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-76-C-0201, June 1978, Unclassified. AD A060 326

16 G.K. Fling, Lightweight Hydraulic System Rod Seal Study, 2-51700-C/9R-52140, Vought Corporation, P.O. H962-AW-611100, June 1979, Unclassified

17 AIR 1362, Physical Properties of Hydraulic Fluids, Society of Automotive Engineers, May 1975

18 AFAPL-TR-76-43, Volumes I thru VIII, Aircraft Hydraulic Systems Dynamic Analysis, McDonnell Aircraft Company, McDonnell Douglas Corporation, Contract F3615-74-C-2016, February 1977, Unclassified

19 G. Amies, R. Levek, P. Lindquist, Computer Simulation of Hydraulic Systems Under Dynamic Conditions, Society of Automotive Engineers, Committee A-6 Conference, September 1977

20 AFAPL-TR-77-63, Aircraft Hydraulic Systems Dynamic Analysis, McDonnell Aircraft Company, McDonnell Douglas Corporation, Contract F33615-74-C-2016, October 1977, Unclassified

21 AFAPL-TR-78-77, Aircraft Hydraulic Systems Dynamic Analysis, McDonnell Aircraft Company, McDonnell Douglas Corporation, Contract F33615-74-C-2016, dated October 1978, Unclassified

13.0 LIST OF ABBREVIATIONS

A/C	aircraft
AFCS	automatic flight control system
BTU/min	British Thermal Units per minute
CIPR	cubic inches per revolution
cpm	cycles per minute
CRES	corrosion resistant
EDU	electronic drive unit
EPP	emergency power package
FC-1	flight control #1
FMEA	failure-modes-and-effects analysis
gal.	gallon
gpm	gallons per minute
GSE	ground support equipment
H.O.	hog-out
Hp	horsepower
Hr	hour
Hz	Hertz (cycles per second)
in.	inch
in^3	cubic inches
lb	pound
L.E.	leading edge
LH	left hand
LHS	lightweight hydraulic system
max.	maximum
MFHBF	mean flight hours between failures

M/N	model number
min	minute (time)
MMH/FH	maintenance man-hours per flight hour
NAAD	North American Aircraft Division
NADC	Naval Air Development Center
NAS	National Aerospace Standard
No.	number
O.D.	outside diameter
ΔP	differential pressure
PC-1	power control #1
P/N	part number
psi	pounds per square inch
psig	pounds per square inch gage pressure
RAT	ram air turbine
RH	right hand
R&M	reliability and maintainability
rpm	revolutions per minute
sec	second (time)
S/N	serial number
SOV	shut-off valve
sys.	system
T.E.	trailing edge
UHT	unit horizontal tail
WUC	work unit code

APPENDIX A

LHS SPECIFICATIONS

General
Specifications

LHS-8800	Hydraulic System Aircraft, 8000 PSI, Design and Installation Requirements for, dated 26 August 1980
LHS-8801	Hydraulic System Components, 8000 PSI, Aircraft, General Specification for, dated 5 August 1980

Component
Specifications

LHS-8810	Pumps, Hydraulic, Variable Delivery, 8000 PSI, dated 25 August 1980
LHS-8811	Accumulators, Hydraulic, Cylindrical, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8812	Cylinders, Hydraulic, 8000 PSI, dated 12 September 1980
LHS-8813	Valves, Aircraft Power Brake, 8000 PSI, dated 15 July 1980
LHS-8814	Valves, Check, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8815	Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 5 Micron Absolute, 8000 PSI, dated 15 June 1980
LHS-8816	Fittings, Fluid Connection, Aircraft, 8000 PSI, dated 15 June 1980
LHS-8817	Valve; Aircraft Hydraulic Flow Regulator, 8000 PSI, dated 2 July 1980
LHS-8818	Hose Assemblies, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8819	Motors, Aircraft Hydraulic, Constant Displacement, 8000 PSI, dated 7 August 1980
LHS-8821	Gland Design; Seals, Hydraulic, 8000 PSI, dated 28 July 1980
LHS-8822	Gage, Pressure, Dial Indicating, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8823	Valve; Aircraft Hydraulic Pressure Reducer, 8000 PSI, dated 1 July 1980
LHS-8824	Snubber, Hydraulic Pressure, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8825	Pressure Switch, Aircraft, Hydraulic, 8000 PSI, dated 23 July 1980

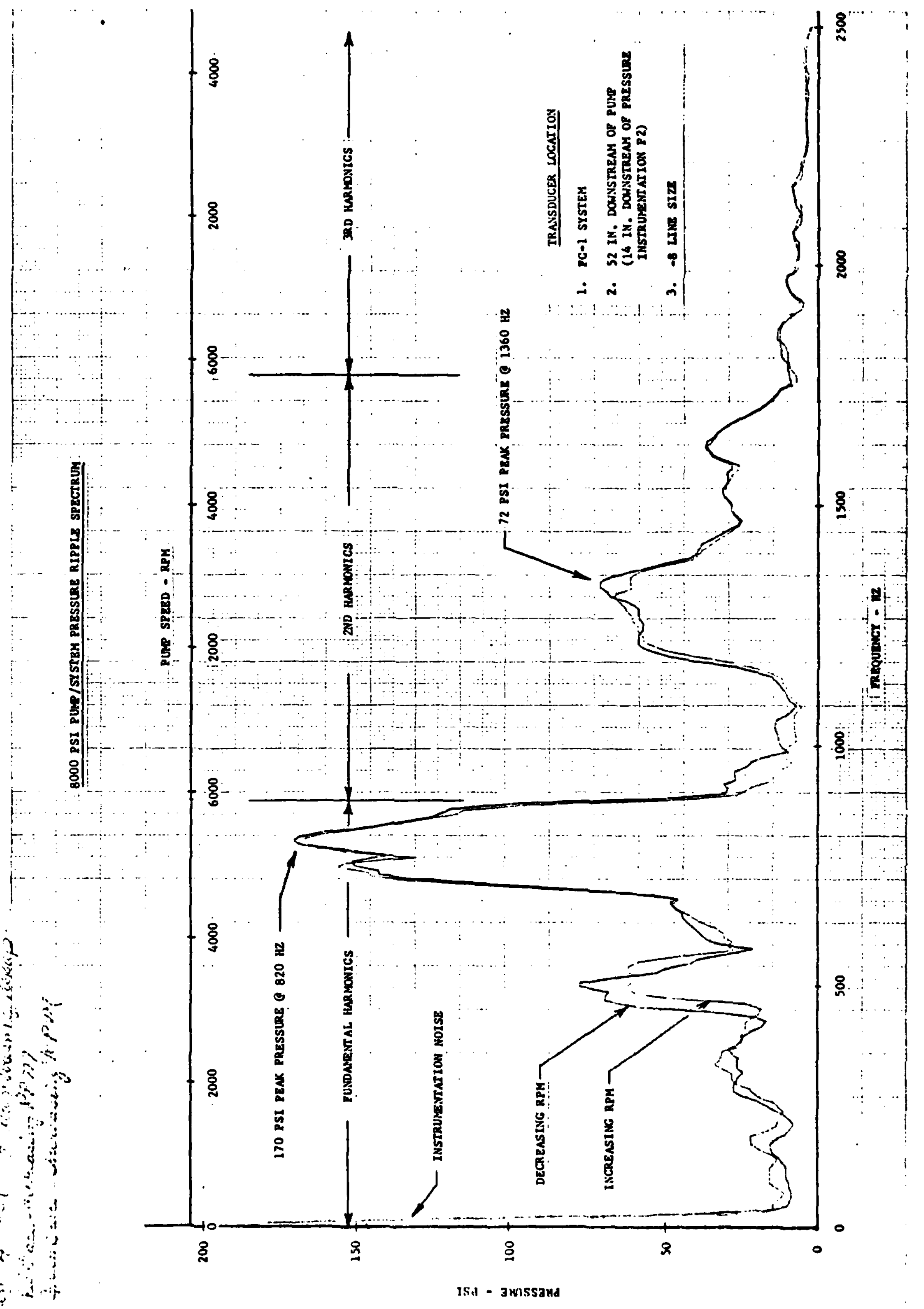
LHS-8826	Transmitter, Pressure, Hydraulic, 8000 PSI, Aircraft, dated 24 June 1980
LHS-8827	Valve; Aircraft Hydraulic Priority, 8000 PSI, dated 28 July 1980
LHS-8828	Coupling, Quick Disconnect, Self-Sealing, Hydraulic, 8000 PSI, Aircraft, dated 19 June 1980
LHS-8829	Valve, Hydraulic Pressure Relief, 8000 PSI, Aircraft, dated 19 June 1980
LHS-8830	Reservoirs; Aircraft, Hydraulic Separated Type, dated 19 June 1980
LHS-8831	Restrictor, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8833	Valve, Bleed, Hydraulic, 8000 PSI, Aircraft, dated 18 August 1980
LHS-8834	Valve, Direct Drive, Electro-hydraulic, Servo Control, 8000 PSI, Aircraft, dated 19 August 1980
LHS-8835	Valve, Aircraft Hydraulic Directional Control, Rotary Selector, 8000 PSI, dated 15 August 1980
LHS-8836	Valve, Shuttle, Hydraulic, 8000 PSI, Aircraft, dated 28 August 1980
LHS-8837	Valve, Hydraulic Control, Solenoid Operated, 8000 PSI, Aircraft, dated 21 August 1980
LHS-8838	Joint, Swivel, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980
LHS-8839	Tubing, Steel, Corrosion Resistant (21-6-9), Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980

Process
Specifications

HA0602-002	Installation of Rigid and Flexible Tubing Assemblies for LHS Systems, dated 19 September 1980
HA0602-003	Fabrication of 3Al-2.5V Titanium Alloy Details for LHS, dated 12 September 1980
HA0607-005	Swage Joining of Titanium Alloy Tubular Joints, dated 19 September 1980
HF0001-002	Control of MIL-H-83282 in Test Stands, Ground Support Equipment and Aircraft Components for LHS Systems, dated 5 September 1980

APPENDIX B

AIR FORCE DATA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PUMP SPEED - RPM
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4000
6000
2000
4000
6000
2000
4000
FUNDAMENTAL HARMONICS
2ND HARMONICS
3RD HARMONICS
170 PSI PEAK PRESSURE @ 820 HZ
72 PSI PEAK PRESSURE @ 1360 HZ
INSTRUMENTATION NOISE
DECREASING RPM
INCREASING RPM
TRANSDUCER LOCATION
1. FC-1 SYSTEM
2. 52 IN. DOWNSTREAM OF PUMP (14 IN. DOWNSTREAM OF PRESSURE INSTRUMENTATION P2)
3. -8 LINE SIZE
FREQUENCY - HZ
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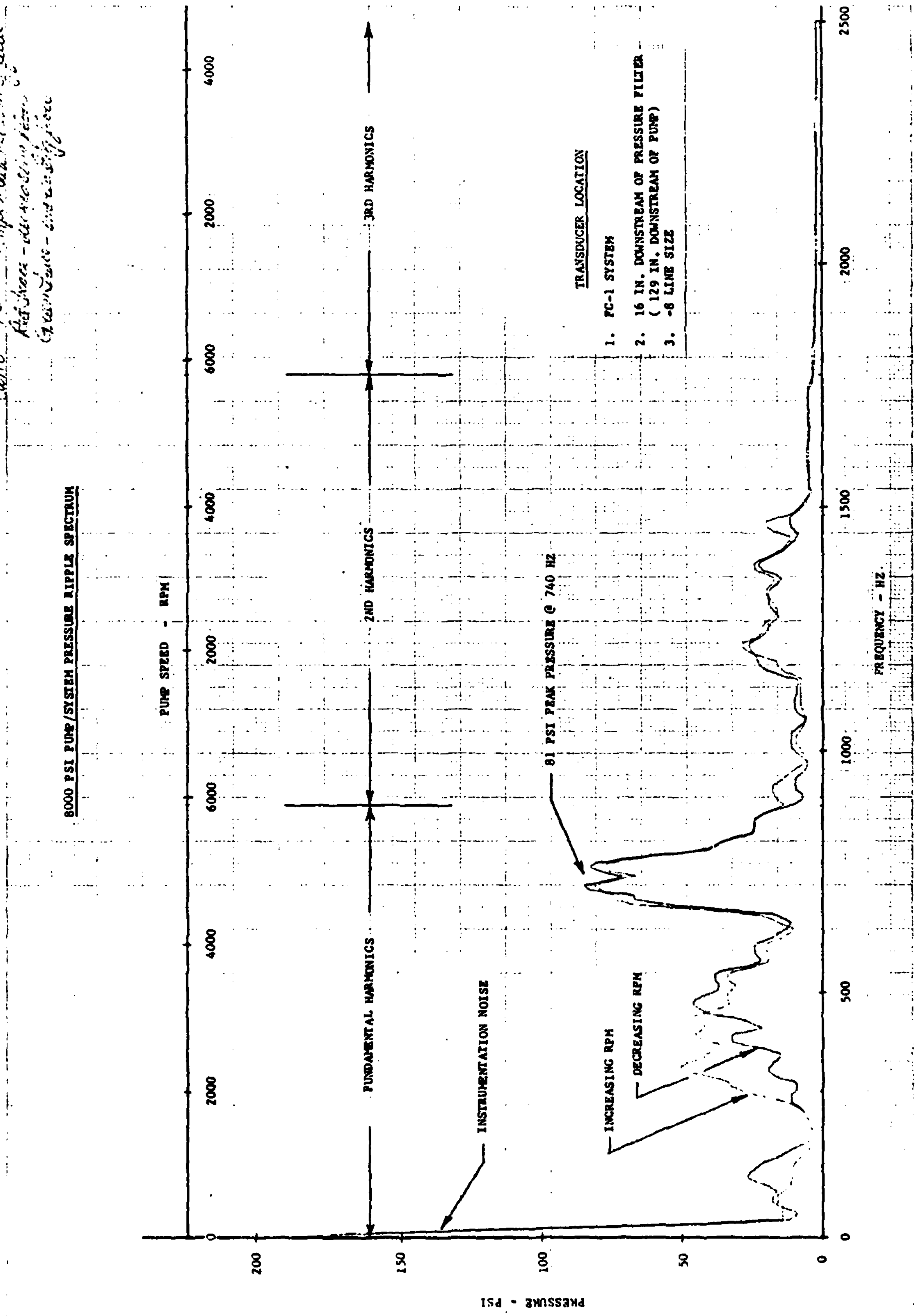
500
1000
1500
2000
2500
PRESSURE - PSI
200
150
100
50
0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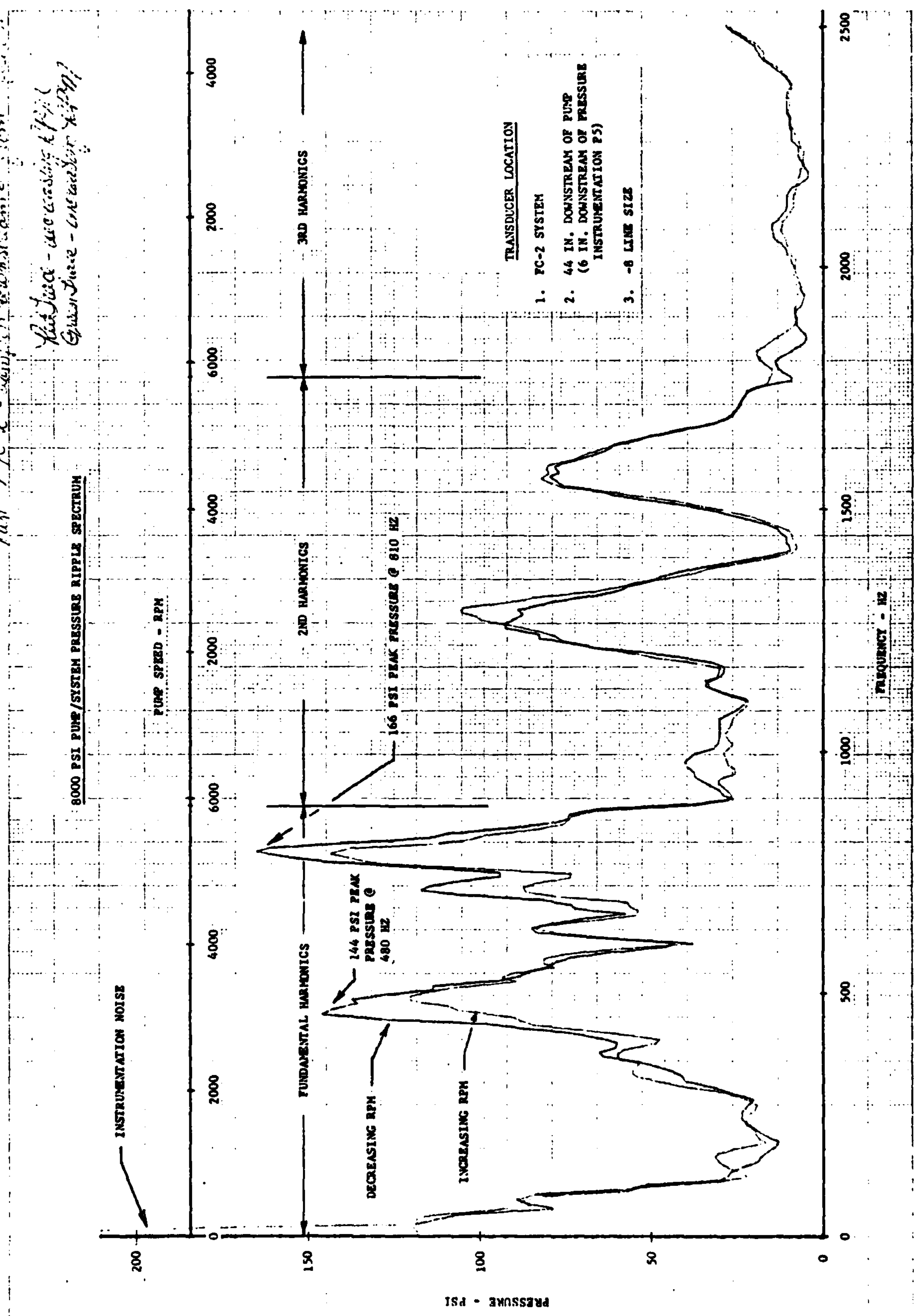
PUMP SPEED - RPM
FUNDAMENTAL HARMONICS
2ND HARMONICS
3RD HARMONICS
INSTRUMENTATION NOISE
INCREASING RPM
DECREASING RPM
81 PSI PEAK PRESSURE @ 740 HZ
TRANSDUCER LOCATION
1. FC-1 SYSTEM
2. 16 IN. DOWNSTREAM OF PRESSURE FILTER
(129 IN. DOWNSTREAM OF PUMP)
3. -8 LINE SIZE
FREQUENCY - HZ
PRESSURE - PSI


8000 PSI PUMP/SYSTEM PRESSURE RIPPLE SPECTRUM
PUMP SPEED - RPM
0
2000
4000
6000
2000
4000
6000
2000
4000
INSTRUMENTATION NOISE
FUNDAMENTAL HARMONICS
2ND HARMONICS
3RD HARMONICS
144 PSI PEAK PRESSURE @ 480 HZ
166 PSI PEAK PRESSURE @ 810 HZ
DECREASING RPM
INCREASING RPM
TRANSDUCER LOCATION
1. FC-2 SYSTEM
2. 44 IN. DOWNSTREAM OF PUMP (6 IN. DOWNSTREAM OF PRESSURE INSTRUMENTATION P5)
3. -8 LINE SIZE
PRESSURE - PSI
200
150
100
50
0
FREQUENCY - HZ
0
500
1000
1500
2000
2500

APPENDIX C

WEIGHT AND SPACE ANALYSIS TABULATIONS

Contents

Table C-1. Component Weight Summary

ITEM*	QTY/AC	DESCRIPTION	WEIGHT, LB EQUIV. 3000 PSI SYSTEM	WEIGHT, LB LHS SYSTEM**
1	2	PUMP	14.90	16.25 (H.O.)
2/3	1 EA	RESERVOIR	25.28	24.26
4	2	RELIEF VALVE, HIGH PRESS	.81	.44
5	2	RELIEF VALVE, LOW PRESS	1.63	.60
6	2	FILTER, PRESSURE	2.75	1.94 (H.O.)
7	2	FILTER, RETURN	2.75	1.40
8	1	FILTER, CASE DR	1.48	1.48
9	1	FILTER, EMER PWR PKG	N/A	N/A
10	2	PRESSURE SNUBBER	.09	.07
11	2	PRESSURE TRANSMITTER/SWITCH	1.45	1.50
12	2	BLEED VALVE	.05	.05
13	1	ACCUMULATOR	3.11	1.94
14	1	PRESSURE GAGE	.18	.12
15	1	SOLENOID VALVE-ACCUM.ISOL.	1.25	(1.40)(H.O.)
16	2	PRESS.DISC-EXTERNAL ACCESS	.67	.31
17	2	SUCTION DISC-EXTERNAL ACCESS	.98	.67
18	2	PRESS. DISC-PUMP	1.00	.60
19	2	SUCTION DISC-PUMP	1.00	.89
20	2	CASE DRAIN DISC-PUMP	.42	.42
21	1	SELECTOR VALVE-SPEED BR	3.30	2.21 (H.O.)
22	-	DELETED	-	-
23	1	EMER. POWER PACKAGE	N/A	N/A
24	1	FLOW SENSITIVE PRESS.REG.	N/A	N/A
25	3	SELECTOR VALVE-AFCS SHUTOFF	.56	1.75 (H.O.)
26	-	DELETED	-	-
27	1	CHARGING VALVE-ACCUM.	.11	.11
28	1	RESTRICTOR-SPEED BRAKE	.40	.04
29	1	RESTRICTOR-L.E. FLAP	.15	.04
30	4	RESTRICTOR-L.E. FLAP O.B. PANEL	.13	.04
31	2	RESTRICTOR-L.E. FLAP INBD. PANEL	.17	.04
32	2	RESTRICTOR-L.E. FLAP INBD. PANEL	.17	.04
33	1	SWIVEL-SPEED BRAKE EXTEND	.69	.69
34	1	SWIVEL-SPEED BRAKE RETRACT	.75	.75
35	1	SWIVEL-EMER. PWR. PKG	N/A	N/A
36	1	SWIVEL-EMER. PWR. PKG	N/A	N/A
37	2	SWIVEL-WING FOLD	1.85	1.75
38/43	-	DELETED	-	-

Table C-1. Component Weight Summary (Cont'd)

ITEM*	QTY/AC	DESCRIPTION	WEIGHT, LB EQUIV. 3000 PSI SYSTEM	WEIGHT, LB LHS SYSTEM**
44	4	CHECK VALVE-RUD.,SP.BR., RET.,FLAP	.07	.07
45	1	CHECK VALVE-SP.BRAKE	.07	.07
46	2	CHECK VALVE-UHT PRESS & RET.	.11	.085
47	1	CHECK VALVE-SP.BRAKE	.10	.08
48	4	CHECK VALVE-RUN AROUND CIRCUITS	.18	.122
49	3	CHECK VALVE-FILTER RUN AROUND	.18	.194
50	1	CHECK VALVE-SP.BRAKE	.35	.209
51	3	CHECK VALVE-RETURN FILTER	.35	.209
52	2	CHECK VALVE-PUMP PRESS	.36	.235
53	2	CHECK VALVE-SYSTEM FILL	.07	.16
54	2	CHECK VALVE-UHT PRESS	.11	.085
55	1	CHECK VALVE-CASE DRAIN	.07	.144
56	1	CHECK VALVE RAT BY-PASS	N/A	N/A
57/63	-	DELETED	-	-
64	1	MANIFOLD, PRESSURE	.58	.491(H.O.)
65	1	MANIFOLD, RETURN	.55	.218(H.O.)
66	1	MANIFOLD, RELIEF VALVE	.79	.69 (H.O.)
67	1	HOSE ASSY-PUMP PRESSURE, FC1	3.14	1.41
68	1	HOSE ASSY-PUMP PRESSURE, FC2	3.14	1.71
69	1	HOSE ASSY-PUMP SUCTION, FC1	2.15	.73
70	1	HOSE ASSY-PUMP SUCTION, FC2	2.15	.78
71	1	HOSE ASSY-CASE DRAIN,FC1	.63	.63
72	1	HOSE ASSY-CASE DRAIN,FC2	.75	.75
73	1	CHECK VALVE-RAT SUCTION	N/A	N/A
74	1	MANIFOLD-ACCUMULATOR	.31	.31
75	1	CHECK VALVE-CASE DRAIN	.07	.144
76	1	MANIFOLD-SUCTION DISCONNECT		
77	1	HOSE ASSY-AILERON PRESSURE	.3	.336
78	1	HOSE ASSY-AILERON RETURN	.3	.331
79	1	HOSE ASSY-AILERON RETURN	.41	.589
80	1	HOSE ASSY-AILERON PRESSURE	.42	.509
81	1	HOSE ASSY-AILERON PRESSURE	.3	.331

Table C-1. Component Weight Summary (Cont'd)

ITEM*	QTY/AC	DESCRIPTION	WEIGHT, LB	
			EQUIV. 3000 PSI SYSTEM	LHS SYSTEM**
82	1	HOSE ASSY-AILERON RETURN	.3	.335
83	1	HOSE ASSY-AILERON RETURN	.42	.578
84	1	HOSE ASSY-AILERON PRESSURE	.39	.522
85	1	SELECTOR VALVE-L.E. FLAP	1.16	(H.O.)
101	2	AILERON ACTUATOR	16.35	15.18 (H.O.)
102	2	SPOILER ACTUATOR	16.35	15.18 (H.O.)
103	1	RUDDER ACTUATOR	8.55	6.44 (H.O.)
104	2	UHT ACTUATOR	33.80	26.02 (H.O.)
105	1	ROLL FEEL ACTUATOR	11.64	10.57 (H.O.)
106	3	AFCS ACTUATOR	15.79	6.59 (H.O.)
107	1	SPEED BRAKE ACTUATOR	46.41	43.29 (H.O.)
108	8	LEADING EDGE FLAP ACTUATOR	6.73	6.18 (H.O.)
109	1	RUDDER SERVO VALVE	3.09	2.86

*See Figure 5
**H.O. = Hog-Out
N/A = Not Applicable

Table C-2. Component Volume Summary

ITEM*	QTY/AC	DESCRIPTION	VOLUME, IN^3	
			EQUIV. 3000 PSI SYSTEM	LHS SYSTEM
1	2	PUMP	171	118
2/3	1 EA	RESERVOIR	817	593
4	2	RELIEF VALVE, HIGH PRESS	7	4
5	2	RELIEF VALVE, LOW PRESS	17	7
6	2	FILTER, PRESSURE	62	24
7	2	FILTER, RETURN	62	31
8	1	FILTER, CASE DR	28	28
9	1	FILTER, EMER PWR PKG	N/A	N/A
10	2	PRESSURE SNUBBER	< 1	< 1
11	2	PRESSURE TRANSMITTER/SWITCH	22	22
12	2	BLEED VALVE	1	1
13	1	ACCUMULATOR	40	25
14	1	PRESSURE GAGE	1	1
15	1	SOLENOID VALVE-ACCUM.ISOL.	15	9
16	2	PRESS.DISC-EXTERNAL ACCESS	9	3
17	2	SUCTION DISC-EXTERNAL ACCESS	12	7
18	2	PRESS. DISC-PUMP	21	6
19	2	SUCTION DISC-PUMP	21	9
20	2	CASE DRAIN DISC-PUMP	5	5
21	1	SELECTOR VALVE-SPEED BR	50	35
22	-	DELETED	-	-
23	1	EMER. POWER PACKAGE	N/A	N/A
24	1	FLOW SENSITIVE PRESS.REG.	N/A	N/A
25	3	SELECTOR VALVE-SAS SHUTOFF	10	13
26	-	DELETED	-	-
27	1	CHARGING VALVE-ACCUM.	< 1	< 1
28	1	RESTRICTOR-SPEED BRAKE	1	< 1
29	1	RESTRICTOR-L.E. FLAP	2	< 1
30	4	RESTRICTOR-L.E. FLAP O.B. PANEL	2	< 1
31	2	RESTRICTOR-L.E. FLAP INBD. PANEL	2	< 1
32	2	RESTRICTOR-L.E. FLAP INBD. PANEL	2	< 1
33	1	SWIVEL-SPEED BRAKE EXTEND	8	10
34	1	SWIVEL-SPEED BRAKE RETRACT	10	12
35	1	SWIVEL-EMER. PWR. PKG	N/A	N/A
36	1	SWIVEL-EMER. PWR. PKG	N/A	N/A
37	2	SWIVEL-WING FOLD	17	16
38/43	-	DELETED	-	-

Table C-2. Component Volume Summary (Cont'd)

ITEM*	QTY/AC	DESCRIPTION	VOLUME, IN^3 EQUIV. 3000 PSI SYSTEM	LHS SYSTEM
44	4	CHECK VALVE-RUD.,SP.BR., RET.,FLAP	<1	<1
45	1	CHECK VALVE-SP.BRAKE	<1	<1
46	2	CHECK VALVE-UHT PRESS & RET.	1	<1
47	1	CHECK VALVE-SP.BRAKE	<1	<1
48	4	CHECK VALVE-RUN AROUND CIRCUITS	1	<1
49	3	CHECK VALVE-FILTER RUN AROUND	1	<1
50	1	CHECK VALVE-SP.BRAKE	1	<1
51	3	CHECK VALVE-RETURN FILTER	1	<1
52	2	CHECK VALVE-PUMP PRESS	1	<1
53	2	CHECK VALVE-SYSTEM FILL	<1	<1
54	2	CHECK VALVE-UHT PRESS	1	<1
55	1	CHECK VALVE-CASE DRAIN	<1	<1
56	1	CHECK VALVE RAT BY-PASS	N/A	N/A
57/63	-	DELETED	-	-
64	1	MANIFOLD, PRESSURE	7	2
65	1	MANIFOLD, RETURN	6	3
66	1	MANIFOLD, RELIEF VALVE	8	5
67	1	HOSE ASSY-PUMP PRESSURE, FC1	30	19
68	1	HOSE ASSY-PUMP PRESSURE, FC2	37	24
69	1	HOSE ASSY-PUMP SUCTION, FC1	27	18
70	1	HOSE ASSY-PUMP SUCTION, FC2	29	19
71	1	HOSE ASSY-CASE DRAIN,FC1	14	14
72	1	HOSE ASSY-CASE DRAIN,FC2	13	13
73	1	CHECK VALVE-RAT SUCTION	N/A	N/A
74	1	MANIFOLD-ACCUMULATOR	3	3
75	1	CHECK VALVE-CASE DRAIN	<1	<1
76	1	MANIFOLD-SUCTION DISCONNECT		
77	1	HOSE ASSY-AILERON PRESSURE	3	3
78	1	HOSE ASSY-AILERON RETURN	3	3
79	1	HOSE ASSY-AILERON RETURN	5	5
80	1	HOSE ASSY-AILERON PRESSURE	5	5
81	1	HOSE ASSY-AILERON PRESSURE	3	3

Table C-2. Component Volume Summary (Cont'd)

ITEM*	QTY/AC	DESCRIPTION	VOLUME, IN^3	
			EQUIV. 3000 PSI SYSTEM	LHS SYSTEM
82	1	HOSE ASSY-AILERON RETURN	3	3
83	1	HOSE ASSY-AILERON RETURN	4	4
84	1	HOSE ASSY-AILERON PRESSURE	5	5
85	1	SELECTOR VALVE-L.E. FLAP	23	
101	2	AILERON ACTUATOR	206	101
102	2	SPOILER ACTUATOR	136	106
103	1	RUDDER ACTUATOR	106	53
104	2	UHT ACTUATOR	446	286
105	1	ROLL FEEL ACTUATOR	77	24
106	3	AFCS ACTUATOR	239	195
107	1	SPEED BRAKE ACTUATOR	658	334
108	8	LEADING EDGE FLAP ACTUATOR	47	26
109	1	RUDDER SERVO VALVE	185	170

*See Figure 5

N/A = Not Applicable

Table C-3. 3000 PSI Plumbing Weight/Volume Breakdown

SUBSYSTEM	TUBING WT DRY	OIL WEIGHT	FITTING WEIGHT	LINE VOLUME
PRESSURE LINES				
POWER GENERATION	11.93	3.50	5.23	157
POWER TRANSMISSION	15.90	4.77	7.14	212
UHT	3.65	1.02	1.02	43
RUDDER	1.11	.28	1.50	13
AILERON	2.72	.69	.73	32
SPOILER	.75	.19	.64	9
ROLL FEEL	.29	.04	.18	3
YAW AFCS	.25	.06	.27	3
ROLL AFCS	.32	.08	.41	4
PITCH AFCS	.07	.02	.14	1
SPEED BRAKE	2.82	1.07	2.24	45
LEADING EDGE FLAP	8.58	2.15	3.67	100
TOTALS	48.39 LB	13.87 LB	23.17 LB	622 IN^3
RETURN & SUCTION LINES				
POWER GENERATION	9.90	6.47	5.02	262
POWER TRANSMISSION	10.86	5.80	4.73	247
UHT	2.58	1.03	.76	44
RUDDER	.27	.12	.36	7
AILERON	2.34	.74	.73	33
SPOILER	.70	.21	.64	9
ROLL FEEL	.22	.07	.21	3
YAW AFCS	.09	.03	.15	2
ROLL AFCS	.14	.07	.21	4
PITCH AFCS	.04	.02	.11	1
SPEED BRAKE	.06	.27	.49	4
LEADING EDGE FLAP	.19	.09	.02	5
TOTALS	27.39 LB	14.92 LB	13.43 LB	621 IN^3

Table C-4. 8000 PSI Plumbing Weight/Volume Breakdown

SUBSYSTEM	TUBING WT DRY	OIL WEIGHT	FITTING WEIGHT	LINE VOLUME
PRESSURE LINES				
POWER GENERATION	4.18	1.35	1.55	70
POWER TRANSMISSION	5.68	1.84	1.43	95
UHT	1.24	.39	.24	21
RUDDER	.45	.14	.23	7
AILERON	1.12	.34	.25	18
SPOILER	.83	.15	.30	49
ROLL FEEL	.63	.09	.20	22
YAW AFCS	.10	.03	.04	2
ROLL AFCS	.13	.04	.06	2
PITCH AFCS	.03	.01	.02	1
SPEED BRAKE	1.06	.34	.38	17
LEADING EDGE FLAP	3.72	1.14	1.46	87
TOTALS	19.17 LB	5.86 LB	6.16 LB	391 IN^3
RETURN & SUCTION LINES				
POWER GENERATION	3.65	2.60	2.52	120
POWER TRANSMISSION	4.14	2.55	1.70	112
UHT	1.01	.42	.24	20
RUDDER	.24	.07	.14	4
AILERON	1.15	.35	.25	19
SPOILER	.81	.16	.30	49
ROLL FEEL	.71	.11	.20	22
YAW AFCS	.07	.02	.06	1
ROLL AFCS	.13	.04	.08	2
PITCH AFCS	.03	.01	.04	1
SPEED BRAKE	.09	.05	.05	2
LEADING EDGE FLAP	.32	.09	.02	3
TOTALS	12.35 LB	6.47 LB	5.60 LB	355 IN^3

TABLE C-5. Actuator Weight Summary

ACTUATOR		EXISTING WEIGHT (REF)	EQUIVALENT 3000 PSI SYSTEM	LHS SYSTEM	WEIGHT REDUCTION
SPOILER	(2)	11.48	16.35 *	15.18	1.17
AILERON	(2)	8.75	16.35 *	15.18	1.17
ROLL FEEL	(1)	6.58	11.64 *	10.57	1.07
AFCS	(3)	15.79	15.79	14.95	.84
UHT	(2)	34.78	33.80 *	26.02	7.78
RUDDER	(1)	7.63	8.55 *	6.44	2.11
RUDDER VALVE	(1)	1.70	3.09 *	2.86	.23
SPEED BR.	(1)	46.41	46.41	43.29	3.12
L.E. FLAP	(8)	6.73	6.73	6.18	.55
TOTALS			303.90 LB	270.21 LB	33.69 LB

*STEEL BARREL OR HOUSING

TABLE C-6. Subsystem Weight/Volume Breakdown

WEIGHT SUMMARY

SUBSYSTEM	3000 PSI	8000 PSI	REDUCTION
POWER GENERATION	201.34	149.55	51.79
DISTRIBUTION SYSTEM	51.69	18.84	32.85
UHT	84.03	57.96	26.07
RUDDER	15.83	10.90	4.93
AILERON	47.15	40.12	7.03
SPOILER	42.08	33.25	8.83
ROLL FEEL	15.58	11.79	3.79
YAW AFCS	17.44	17.10	.34
ROLL AFCS	17.79	17.26	.53
PITCH AFCS	16.95	16.92	.03
SPEED BRAKE	65.85	52.25	13.60
LEADING EDGE	79.59	60.77	18.82
TOTALS	655.32 LB	486.71 LB	168.61 LB

VOLUME SUMMARY

SUBSYSTEM	3000 PSI	8000 PSI	REDUCTION
POWER GENERATION	3237	2081	1156
DISTRIBUTION SYSTEM	582	263	319
UHT	989	619	370
RUDDER	323	238	85
AILERON	440	284	156
SPOILER	364	314	50
ROLL FEEL	106	70	36
YAW AFCS	257	212	45
ROLL AFCS	261	214	47
PITCH AFCS	253	210	43
SPEED BRAKE	803	420	377
LEADING EDGE	558	282	276
TOTALS	8173 IN^3	5207 IN^3	2960 IN^3

TABLE C-7. Major Elements Weight Summary

ITEM	EQUIVALENT 3000 PSI SYSTEM	PERCENT OF SYS.WT.	LHS SYSTEM	PERCENT RED. IN COMP.WT.
PUMP	29.80	4.5	32.50	+ 9.1
RESERVOIR	50.56	8.2	48.52	- 4.0
ACTUATORS	303.90	46.2	270.21	-11.1
TUBING	75.90	11.6	31.37	-58.7
OIL	76.04	11.6	38.91	-48.8
FITTINGS	36.89	5.6	11.21	-69.6
MISC. COMP.	82.23	12.3	53.99	-34.3
TOTALS	655.32 LB	100%	486.71 LB	

TABLE C-8. Configuration Adjustments Weight Summary

	EQUIVALENT 3000 PSI SYSTEM	LHS SYSTEM
BASIC SYSTEM	655.3 LB	486.7 LB
CONFIGURATION ADJUSTMENTS		
RESERVOIR	- 7.3	-11.6
UHT ACTUATOR	0	- 2.0
CASTINGS/FORGINGS	0	- 6.3
SHRINK-FIT VALVES	0	- 7.4
INCREASED PUMP SPEED	- 3.6	- 9.7
TOTALS	- 10.9 LB	-37.0 LB
ADJUSTED SYSTEM WT.	644.4 LB	449.7 LB

APPENDIX D

LHS RELIABILITY PREDICTIONS

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
1	PUMP, FC-1 & FC-2 SYS	2	PV3-047-1	1220	-	45116 (215-22119)	1155	5.5	-	VICKERS FMEA REV. SEPT. 18, 1979
2	RESERVOIR, FC-1	1	83-00241-	3976	4360	45113 (215-32108-3)	3800	4.6	14.7	DEV. RESVR. SAME SIZE AS 3000 PSI. PROD. WILL REDUCE SIZE, RESULTING IN A CORRESPONDING DECREASE IN SCORING/SCRATCH-ING.
3	RESERVOIR, FC-2	1	83-00241-	3976	4360	45113 (215-32108-3)	3800	4.6	14.7	
4	RELIEF VALVE, FC-1 & FC-2 SYS	2	1257 1258	4909	-	4521A (215-32345)	4909	0	-	
5	RELIEF VALVE, RESERVOIR, FC-1 & FC-2 SYS	2		12623	-	45112 (215-32359)	12623	0	-	
6	FILTER, PRESS FC-1 & FC-2 SYS	2	AD-A640-8341	793	-	45118 (215-32306)	793	0	-	
7	FILTER, RETURN, FC-1 & FC-2 SYS	2	M8815/4A-8	1390	-	4511E 4521F (210-82500)	1390	0	-	
8	FILTER, PUMP BYPASS, FC-2 SYS	1	M8815/4A-6	2780	-	4511E 4521F (210-82500)	2780	0	-	

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
9	FILTER, EMERG PWR. PACKAGE, FC-2 SYS	1	AD3258-8HV	N/A	N/A	91134/49A27 (215-32484-1)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.
10	PRESSURE SNUBBER, FC-1 & FC-2 SYS	2	95239	88362	-	45133 (S-1442)	88362	0	-	
11	PRESSURE XMTR & SWITCH, FC-1 & FC-2 SYS	2	18-2143	1691	-	45131/231 (216-32499)	1691	0	-	
12	BLEED VALVE, FC-1 & FC-2 SYS	2	40121	74403	-	14759 (CVC-4202)	74403	0	-	
13	ACCUMULATOR, FC-2 SYS	1	3321471	12000	-	4511B (215-32523-4)	16066	-25.0	-	POSSIBLE SEAL PROBLEMS ON PISTON WHICH WOULD CAUSE AERATING OF FLUID.
14	PRESSURE GAGE, FC-2 SYS	1	1218-63-1	26955	-	45411.1 (6901-18-1)	26955	0	-	
15	SHUT-OFF VALVE, SOL OPERATED, FC-2, PRESS DUMP	1		70689	-	4531H (707394) (215-22308)	70689	0	-	
16	QUICK DISC, PRESS, GR. COUPLING HALF, FC-1 & FC-2 SYS	2	AE80942H	5122	-	4511C 4521C (215-32587)	5122	0	-	8000 PSI VERSION REQUIRES SIX TURNS TO COUPLE. SEAL PROVISIONS SAME AS 3000 PSI.

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
17	QUICK DISC, SUCTION GR. COUPLING HALF, FC-1 & FC-2 SYS	2	3018-54-12D 01553-57-120	7362	-	4511D 4521D (215-32351)	7362	0	-	SEE ITEM 16
18	QUICK DISC, PUMP PRESS, HOSE & BLKHD HALF, FC-1 & FC-2	2	AE80943H AE80944H	1370	-	45114 45214 (210-82234)	1370	0	-	SEE ITEM 16
19	QUICK DISC, PUMP SUCTION HOSE & BLKHD HALF, FC-1 & FC-2	2	AE94951J AE94952J	1370	-	45114 45214 (210-82234)	1370	0	-	SEE ITEM 16
20	QUICK DISC, PUMP C. DR., HOSE & BLKHD HALF, FC-1 & FC-2	2	AE94951G AE94952G	1370	-	45114 45214 (210-82234)	1370	0	-	SEE ITEM 16
21	SELECTOR VALVE, SOL OPERATED, FC-1, SPD BRAKE	1	3321472	1851	-	14621 (215-32106)	1851	0	-	
22	VALVE, UNLOADING, MAN OPERATED, FC-1, SPD BRAKE	1		3021	-	14626 (707074)	3021	0	-	
23	EMERG POWER PACKAGE, FC-2 SYS	1	953812-4-1	N/A	N/A	91131 (954034)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.
24	PRESS. REGULATOR, EMERG. PWR. PACKAGE, FC-2 SYS	1	EA50002-24	N/A	N/A	91133 (215-22131)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
25	SELECTOR VALVE, SOL OPERATED, SAS, FC-1 & FC-2 SYS	3	3321473	22090	-	57588 57581 5758D (215-32331)	22090	0	-	
26	SELECTOR VALVE, MAN OPERATED, L.E. FLAP, FC-2 SYS	1		3184	-	14751 (HP943100)	3184	0	-	
27	CHARGING VALVE, PNEUMATIC, FC-2 ACCUM	1		144594	-	45411.3 (216-32509)	144594		-	LAB DEVEL. USING A 5000 PSI DESIGN
28	RESTRICTOR, TWO WAY, SPD BRAKE, FC-1 SYS	1	REFX0380-250A	28860	-	1475E (215-32320)	28860	0	-	
29	RESTRICTOR, ONE WAY, L.E. FLAP, FC-2 SYS	1		28860	-	1475E (215-32320)	28860	0	-	
30	RESTRICTOR, ONE WAY, L.E. FLAP OUTB'D, FC-2 SYS	4		7215	-	1475E (215-32320)	7215	0	-	
31	RESTRICTOR, ONE WAY, L.E. FLAP INB'D, RETRACT, FC-2 SYS	2		14430	-	1475E (215-32320)	14430	0	-	
32	RESTRICTOR, ONE WAY, L.E. FLAP INB'D, EXTEND, FC-2 SYS	2		14430	-	1475E (215-32320)	14430	0	-	

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
33	SWIVEL JOINT, SPD BRAKE, EXTEND, FC-1 SYS	1		6730	-	14625 (215-32334)	6730	0	-	SWIVEL JOINTS NOT DEVELOPED IN PHASE I. SEALS NOT DECIDED "O" RINGD NOT ACCEPTABLE.
34	SWIVEL JOINT, SPD BRAKE, RETRACT, FC-1 SYS	1		6730	-	14625 (215-32334)	6730	0	-	SEE ITEM 33
35	SWIVEL JOINT, EMERG PWR PACK, (RAT) FC-2 SYS	1		N/A	N/A	91132 (215-23307)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.
36	SWIVEL JOINT, EMERG PWR PACK, (RAT) FC-2 SYS	1		N/A	N/A	91132 (215-23307)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.
37	SWIVEL JOINT, WING FOLD, FC-1 & FC-2 SYS	2		10395	-	14237 (215-72042)	10395	0	-	SEE ITEM 33
38	SWIVEL JOINT, WING CONNECT, FC-2 PRESS & RETURN	2		24772	-	1475A (216-32201)	24772	0	-	SEE ITEM 33
39	SWIVEL JOINT, L.E. FLAP WING CONNECT, FC-2 (FUS SIDE)	2		24772	-	1475A (216-32201)	24772	0	-	SEE ITEM 33
40	SWIVEL JOINT, L.E. FLAP WING CONNECT, FC-2 (WING SIDE)	2		24772	-	1475A (216-32201)	24772	0	-	SEE ITEM 33

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
41	SWIVEL JOINT, L.E. FLAP ACTR, OUTBD, FC-2 (WING SIDE)	8		11,364	-	1475A (215-82306) (215-72310) (216-32201)	6193	83.5	-	TO BE REPLACED BY COILED TUBING
42	SWIVEL JOINT, L.E. FLAP ACTR, OUTBD, FC-2 (ACTR SIDE)	8		11,364	-	1475A (215-82306) (215-72310) (216-32201)	6193	83.5	-	SEE ITEM 41
43	SWIVEL JOINT, L.E. FLAP ACTR, INBD, FC-2 (WING SIDE)	8		11,364	-	1475A (215-82306) (215-72310) (216-32201)	6193	83.5	-	SEE ITEM 41
44	CHECK VALVE, PRESS (TYPE I - 3 SIZE) SPD (SPD BRAKE)	3	95202-1	49605	-	14759 (CVC-4120)	49605	0	-	
45	CHECK VALVE, PRESS (TYPE IIB - 3 SIZE) SPD BRAKE	2	95200-1	74408	-	14759 (CVC-4120)	74408	0	-	
46	CHECK VALVE, PRESS (TYPE IIB - 4 SIZE) [illegible]	4	95202-2	37204	-	14759 (CVC-4120)	37204	0	-	
47	CHECK VALVE, PRESS (TYPE IIB - 4 SIZE) SPD BRAKE	1	95200-2	148816	-	14759 (CVC-4120)	148816	0	-	
48	CHECK VALVE, PRESS (TYPE I - 6 SIZE)	4	95202-4	37204	-	14759 (CVC-4120)	37204	0	-	

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
49	CHECK VALVE, PRESS (TYPE I - 8 SIZE) [illegible] ISOL	1	95202-5	148816	-	14759 (CVC-4120)	148816	0	-	
50	CHECK VALVE, PRESS (TYPE IIB - 8 SIZE) STD BRAKE	1	95200-5	148816	-	14759 (CVC-4120)	148816	0	-	
51	CHECK VALVE, PRESS (TYPE IA - 3 SIZE) RAT [illegible] OUTLET	1	952XX-5	148816	-	14759 (CVC-4120)	148816	0	-	
52	CHECK VALVE, PRESS (TYPE IIIB - 8 SIZE) [illegible]	2	95201-5	74408	-	14759 (CVC-4120)	74408	0	-	
53	CHECK VALVE, RETURN - 3 SIZE FILL & L.E. FLAP	3		49605	-	14759 (CVC-4120)	49605	0	-	
54										NOT USED
55	CHECK VALVE, RETURN - [illegible] SIZE CASE DRAIN	2		74408	-	14759 (CVC-4120)	74408	0	-	
56	CHECK VALVE, RETURN, - 8 SIZE	5		29763	-	14759 (CVC-4120)	29763	0	-	

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
57	EXTENSION UNIT, ROLL FEEL, FC-2 PRESS & RETURN	2		45455	-	14234 (215-72301)	1498	2934	-	TO BE REPLACED BY COILED TUBING
58	EXTENSION UNIT, ROLL FEEL, FC-1 RETURN	1		90909	-	14234 (215-32336) (215-32337)	2996	2934	-	SEE ITEM 57
59	EXTENSION UNIT, ROLL FEEL, FC-1 PRESS	1		90909	-	14234 (215-32336) (215-32337)	2996	2934	-	SEE ITEM 57
60	EXTENSION UNIT, SPOILER, FC-1 PRESS & RETURN	4		22727	-	1423C (215-72304) (215-72303)	1602	1319	-	SEE ITEM 57
61	EXTENSION UNIT, SPOILER, FC-2 PRESS & RETURN	4		22727	-	1423C (215-72304) (215-72303)	1602	1319	-	SEE ITEM 57
62	EXTENSION UNIT, AILERON, FC-1 PRESS, FC-1 & FC-2 RETURN	6		15152	-	14238 (215-82302) (215-82303)	556	2625	-	SEE ITEM 57
63	EXTENSION UNIT, AILERON, FC-2 PRESS	2		45455	-	14238 (215-82302) (215-82308)	1668	2625	-	SEE ITEM 57
64	MANIFOLD, FC-1 PRESS	1		-	-	45119	-	-	-	

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF DEV	MFHBF PROD	WUC (P/N)	MFHBF PER SYSTEM	DEV	PROD	
65	MANIFOLD, FC-1 RETURN	1		-	-	45119	-	-	-	
66	MANIFOLD, FC-1 RELIEF VALVE	1	8696-581201	-		45119	-			
67	HOSE ASSY, PUMP PRESS FC-1	1		17672	-	4511X	17672	0	-	
68	HOSE ASSY, PUMP PRESS, FC-2	1		13594	-	4521R (218-42502)	13594	0	-	
69	HOSE ASSY, PUMP SUCTION, FC-1	1		25246	-	4511Y (218-42501)	25246	0	-	
70	HOSE ASSY, PUMP SUCTION, FC-2	1		9063	-	4521Q (218-42501)	9063	0	-	
71	HOSE ASSY, PUMP CASE DRAIN, FC-1	1		23563		4511Z (218-42502)	23563	0	-	
72	HOSE ASSY, PUMP CASE DRAIN, FC-2	1		13594	-	4521R (218-42502)	13594	0	-	

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
73	CHECK VALVE, RETURN, RAT SECTION	1		148816	-	14759 (CVC-4120)	148816	0	-	
74	MANIFOLD, FC-2 ACCUMULATOR	1		-	-	45419	-	-	-	

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS P/N	8000 PSI SYS MFHBF DEV	8000 PSI SYS MFHBF PROD	3000 PSI SYS WUC (P/N)	3000 PSI SYS MFHBF PER SYSTEM	% MFHBF CHANGE 3000 VS 8000 DEV	% MFHBF CHANGE 3000 VS 8000 PROD	REMARKS/RATIONALE
101	AILERON ACTUATOR	2	83-00221	1101		14233 (215-82031)	807	36.5		
102	SPOILER ACTUATOR	2	83-00271	2645		1423B (215-72031)	2067	28.0		
103	RUDDER ACTUATOR	1	8696-587100	3351		14431 (CV15-151039)	3073	9.0		
104	UNIT HORIZONTAL TAIL ACTUATOR	2	83-00211	1725		14531 (CV15-601051)	1741	-0.9		
105	ROLL FEEL [illegible] ACTUATOR	1	83-00251	3324		14231 (210-32277)	2761	20.4		
106	[illegible] PILOT ACTUATOR ROLL, YAW, PITCH	3	83-00231	997		5758A&B 5758E&F 57582&3 (210-32230)	696	43.3		
107	SPEED BRAKE ACTUATOR	1	83-00201	7864		14622 (215-32031)	8621	-8.8		
108	LEADING EDGE FLAP ACTUATOR	8	83-00261	3113		14753 14755 (215-72033)	2783	11.8		

LHS RELIABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MFHBF CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MFHBF		WUC (P/N)	MFHBF			
				DEV	PROD		PER SYSTEM	DEV	PROD	
109	RUDDER SERVO VALVE	1		3884	-	14432 (215-62100-4)	3884	0	-	
-	TUBING & FITTINGS			1386	-	1423D 14239 14433 14439 14627 14629 1475F 14759 14769 45119 45139 45319 45329 45419	693	100%	-	PERMANENT LINES & FITTINGS IS ESTIMATED TO REDUCE FAILURE RATE 50%.
			TOTAL	65.4			TOTAL 45.4	44%		

APPENDIX E

LHS MAINTAINABILITY PREDICTIONS

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MHH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH		WUC (P/N)	MMH/FH			
				DEV	PROD		PER SYSTEM	DEV	PROD	
1	PUMP, FC-1 & FC-2 SYS	2	PV3-047-1	.0173	-	45116 (215-22119)	.018288	-5.4	-	Proportional to change in failure rate.
2	RESERVOIR, FC-1	1	83-00241-	.0031	.0028	45113 (215-32108-3)	.003215	-4.4	-12.5	
3	RESERVOIR, FC-2	1	83-00241-	.0031	.0028	45113 (215-32108-3)	.003215	-4.4	-12.5	
4	RELIEF VALVE, FC-1 & FC-2 SYS	2	1257 1258	.0034	-	4521A (215-32345)	.00342	0	-	
5	RELIEF VALVE, RESERVOIR, FC-1 & FC-2 SYS	2		.0009	-	45112 (215-32359)	.000928	0	-	
6	FILTER, PRESS FC-1 & FC-2 SYS	2	AD-A640-8341	.0093	-	45118 (215-32306)	.009256	0	-	
7	FILTER, RETURN, FC-1 & FC-2 SYS	2	M8815/4A8	.0125	-	4511E 4521F (210-82500)	.012545	0	-	
8	FILTER, PUMP BYPASS, FC-2 SYS	1	M8815/4A-6	.0063	-	4511E 4521F (210-82500)	.006273	0	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH		WUC (P/N)	MMH/FH			
				DEV	PROD		PER SYSTEM	DEV	PROD	
9	FILTER, EMERG PWR. PACKAGE, FC-2 SYS	1	AD3258-8HV	N/A	N/A	91134/49A27 (215-32484-1)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.
10	PRESSURE SNUBBER, FC-1 & FC-2 SYS	2	95239	.00002	-	45133 (S-1442)	.000016	0	-	Proportional to change in failure rate.
11	PRESSURE XMTR & SWITCH, FC-1 & FC-2 SYS	2	18-2143	.0062	-	45131/231 (216-32499)	.0062	0	-	
12	BLEED VALVE, FC-1 & FC-2 SYS	2	40121	.0002	-	14759 (CVC-4202)	.00018	0	-	
13	ACCUMULATOR, FC-2 SYS	1	331471	.0010	-	4511B (215-32523-4)	.00074	35.1	-	
14	PRESSURE GAGE, FC-2 SYS	1	1218-63-1	.00006	-	45411.1 (6901-18-1)	.000064	0	-	
15	SHUT-OFF VALVE, SOL OPERATED, FC-2, PRESS DUMP	1		.0004	-	4531H (7U7394) (215-22308)	.00036	0	-	
16	QUICK DISC, PRESS, GR. COUPLING HALF, FC-1 & FC-2 SYS	2	AE80942H	.0015	-	4511C 4521C (215-32587)	.00146	0	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH		WUC (P/N)	MMH/FH			
				DEV	PROD		PER SYSTEM	DEV	PROD	
17	QUICK DISC, SUCTION GR. COUPLING HALF, FC-1 & FC-2 SYS	2	3018-54-12D 01553-57-120	.0008	-	4511D 4521D (215-32351)	.00076	0	-	
18	QUICK DISC, PUMP LINES, HOSE & BLKHD HALF, FC-1 & FC-2	2	AE80943H AE80944H	.0017	-	45114 45214 (210-82234)	.00166	0	-	
19	QUICK DISC, PUMP [illegible], HOSE & BLKHD HALF, FC-1 & FC-2	2	AE94951J AE94952J	.0017	-	45114 45214 (210-82234)	.00166	0	-	
20	QUICK DISC, PUMP [illegible], HOSE & BLKHD HALF, FC-1 & FC-2	2	AE94951G AE94952G	.0017	-	45114 45214 (210-82234)	.00166	0	-	
21	SELECTOR VALVE, SOL OPERATED, FC-1, SPD BRAKE	1	3321472	.0069	-	14621 (215-32106)	.006859	0	-	
22	VALVE, UNLOADING, MAN OPERATED, FC-1, SPD BRAKE	1		.0041	-	14626 (7U7074)	.00412	0	-	
23	EMERG POWER PACKAGE, FC-2 SYS	1	953812-4-1	N/A	N/A	91131 (954034)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.
24	PRESS. REGULATOR, EMERG. PWR. PACKAGE, FC-2 SYS	1	EA50002-24	N/A	N/A	91133 (215-22131)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH		WUC (P/N)	MMH/FH			
				DEV	PROD		PER SYSTEM	DEV	PROD	
25	SELECTOR VALVE, SOL OPERATED, SAS, FC-1 & FC-2 SYS	3	3321473	.0027	-	57588 57581 5758D (215-32331)	.00267	0	-	Proportional to change in failure rate.
26	SELECTOR VALVE, MAN OPERATED, L.E. FLAP, FC-2 SYS	1		.0047	-	14751 (HP943100)	.004712	0	-	
27	CHARGING VALVE, PNEUMATIC, FC-2 ACCUM	1		.0001	-	45411.3 (216-32509)	.000106	0	-	
28	RESTRICTOR, TWO WAY, SPD BRAKE, FC-1 SYS	1	REFX0380-250A	.0134	-	14629 1475E (215-32320)	.001367	0	-	
29	RESTRICTOR, ONE WAY, L.E. FLAP, FC-2 SYS	1		.0134	-	1475E (215-32320)	.001367	0	-	
30	RESTRICTOR, ONE WAY, L.E. FLAP OUTB'D, FC-2 SYS	4		.0055	-	1475E (215-32320)	.005468	0	-	
31	RESTRICTOR, ONE WAY, L.E. FLAP INB'D, RETRACT, FC-2 SYS	2		.0027	-	1475E (215-32320)	.002734	0	-	
32	RESTRICTOR, ONE WAY, L.E. FLAP INB'D, EXTEND, FC-2 SYS	2		.0027	-	1475E (215-32320)	.002734	0	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS P/N	8000 PSI SYS MMH/FH DEV	8000 PSI SYS MMH/FH PROD	3000 PSI SYS WUC (P/N)	3000 PSI SYS MMH/FH PER SYSTEM	% MMH/FH CHANGE 3000 VS 8000 DEV	% MMH/FH CHANGE 3000 VS 8000 PROD	REMARKS/RATIONALE
33	SWIVEL JOINT, SPD BRAKE, EXTEND, FC-1 SYS	1		.0030	-	14625 (215-32334)	.0030165	0	-	
34	SWIVEL JOINT, SPD BRAKE, RETRACT, FC-1 SYS	1		.0030	-	14625 (215-32334)	.0030165	0	-	
35	SWIVEL JOINT, EMERG PWR PACK, (RAT) FC-2 SYS	1		N/A	N/A	91132 (215-23307)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.
36	SWIVEL JOINT, EMERG PWR PACK, (RAT) FC-2 SYS	1		N/A	N/A	91132 (215-23307)	N/A	N/A	N/A	EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.
37	SWIVEL JOINT, WING FOLD, FC-1 & FC-2 SYS	2		.0001	-	14237 (215-72042)	.000141	0	-	PROPORTIONAL TO CHANGE IN FAILURE RATE
38	SWIVEL JOINT, WING CONNECT, FC-2 PRESS & RETURN	2		.0004	-	1475A (216-32201)	.0003626	0	-	
39	SWIVEL JOINT, L.E. FLAP WING CONNECT, FC-2 (FUS SIDE)	2		.0004	-	1475A (216-32201)	.0003626	0	-	
40	SWIVEL JOINT, L.E. FLAP WING CONNECT, FC-2 (WING SIDE)	2		.0004	-	1475A (216-32201)	.0003626	0	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH		WUC (P/N)	MMH/FH			
				DEV	PROD		PER SYSTEM	DEV	PROD	
41	SWIVEL JOINT, L.E. FLAP ACTR, OUTBD, FC-2 (WING SIDE)	8		.0008	-	1475A (215-82306) (215-72310) (216-32201)	.00145	-45.5	-	
42	SWIVEL JOINT, L.E. FLAP ACTR, OUTBD, FC-2 (ACTR SIDE)	8		.0008	-	1475A (215-82306) (215-72310) (216-32201)	.00145	-45.5	-	
43	SWIVEL JOINT, L.E. FLAP ACTR, INBD, FC-2 (WING SIDE)	8		.0008	-	1475A (215-82306) (215-72310) (216-32201)	.00145	-45.5	-	
44	CHECK VALVE, PRESS (TYPE I - 3 SIZE) RH (STD BRAKE)	3	95202-1	.0015	-	14759 (CVC-4120)	.001484	0	-	
45	CHECK VALVE, PRESS (TYPE IIB - 3 SIZE) STD BRAKE	2	95200-1	.0010	-	14759 (CVC-4120)	.000989	0	-	
46	CHECK VALVE, PRESS (TYPE IIB - 4 SIZE) LHT	4	95202-2	.0020	-	14759 (CVC-4120)	.001978	0	-	
47	CHECK VALVE, PRESS (TYPE IIB - 4 SIZE) STD BRAKE	1	95202-2	.0005	-	14759 (CVC-4120)	.0004945	0	-	
48	CHECK VALVE, PRESS (TYPE I - 6 SIZE)	4	95202-4	.0020	-	14759 (CVC-4120)	.001978	0	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH		WUC (P/N)	MMH/FH			
				DEV	PROD		PER SYSTEM	DEV	PROD	
49	CHECK VALVE, PRESS (TYPE I - 8 SIZE) ACCUM ISOL	1	95202-5	.0005	-	14759 (CVC-4120)	.0004945	0	-	
50	CHECK VALVE, PRESS (TYPE IIB - 8 SIZE) [illegible] BRAKE	1	95200-5	.0005	-	14759 (CVC-4120)	.0004945	0	-	
51	CHECK VALVE, PRESS (TYPE IA - 6 SIZE) FAT REC OUTLET	1	952XX-5	.0005	-	14759 (CVC-4120)	.0004945	0	-	
52	CHECK VALVE, PRESS (TYPE IIIB - 8 SIZE) PUMP PRESS	2	95201-5	.0010	-	14759 (CVC-4120)	.000989	0	-	
53	CHECK VALVE, RETURN - 3 SIZE FILL & L.E. FLAP	3		.0015	-	14759 (CVC-4120)	.001484	0	-	
54										NOT USED
55	CHECK VALVE, RETURN - 6 SIZE CASE DRAIN	2		.0010	-	14759 (CVC-4120)	.000989	0	-	
56	CHECK VALVE, RETURN, - 8 SIZE	5		.0025	-	14759 (CVC-4120)	.0024725	0	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS P/N	8000 PSI SYS MMH/FH DEV	8000 PSI SYS MMH/FH PROD	3000 PSI SYS WUC (P/N)	3000 PSI SYS MMH/FH PER SYSTEM	% MMH/FH CHANGE 3000 VS 8000 DEV	% MMH/FH CHANGE 3000 VS 8000 PROD	REMARKS/RATIONALE
57	EXTENSION UNIT, ROLL FEEL, FC-2 PRESS & RETURN	2		.0003	-	14234 (215-72301)	.008344	-96.7	-	
58	EXTENSION UNIT, ROLL FEEL, FC-1 RETURN	1		.0001	-	14234 (215-32336) (215-32337)	.004172	-96.7	-	
59	EXTENSION UNIT, ROLL FEEL, FC-1 PRESS	1		.0001	-	14234 (215-32336) (215-32337)	.004172	-96.7	-	
60	EXTENSION UNIT, SPOILER, FC-1 PRESS & RETURN	4		.0005	-	1423C (215-72304) (215-72303)	.006749	-93.0	-	
61	EXTENSION UNIT, SPOILER, FC-2 PRESS & RETURN	4		.0005	-	1423C (215-72304) (215-72303)	.006749	-93.0	-	
62	EXTENSION UNIT, AILERON, FC-1 PRESS, FC-1 & FC-2 RETURN	6		.0007	-	14238 (215-82302) (215-82308)	.019627	-96.3	-	
63	EXTENSION UNIT, AILERON, FC-2 PRESS	2		.0002	-	14238 (215-82302) (215-82308)	.006542	-96.3	-	
64	MANIFOLD, FC-1 PRESS	1		-	-	45119	-	-	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH DEV	MMH/FH PROD	WUC (P/N)	MMH/FH PER SYSTEM	DEV	PROD	
65	MANIFOLD, FC-1 RETURN	1		-	-	45119	-	-	-	
66	MANIFOLD, FC-1 RELIEF VALVE	1	8696-581201	-	-	45119	-	-	-	
67	HOSE ASSY, PUMP PRESS FC-1	1		.00007	-	4511X	.0000673	0	-	
68	HOSE ASSY, PUMP PRESS, FC-2	1		.0006		4521R (218-42502)	.0006336	0	-	
69	HOSE ASSY, PUMP SUCTION, FC-1	1		.0005		4511Y (218-42501)	.0005423	0	-	
70	HOSE ASSY, PUMP SUCTION, FC-2	1		.0005		4521Q (218-42501)	.000506	0	-	
71	HOSE ASSY, PUMP CASE DRAIN, FC-1	1		.0003		4511Z (218-42502)	.0003368	0	-	
72	HOSE ASSY, PUMP CASE DRAIN, FC-2	1		.0006		4521R (218-42502)	.0006336	0	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH		WUC (P/N)	MMH/FH			
				DEV	PROD		PER SYSTEM	DEV	PROD	
73	CHECK VALVE, RETURN, PMT SUCTION	1		.0005	-	14759 (CVC-4120)	.0004945	0	-	
74	MANIFOLD, FC-2 ACCUMULATOR	1		-	-	45419	-	-	-	

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH DEV	MMH/FH PROD	WUC (P/N)	MMH/FH PER SYSTEM	DEV	PROD	
101	AILERON ACTUATOR	2	83-00221	.0228	-	14233 (215-82031)	.031142	-26.7	-	
102	SPOILER ACTUATOR	2	83-00271	.0063	-	1423B (215-72031)	.008052	-21.9	-	
103	RUDDER ACTUATOR	1	8696-587100	.0082		14431 (CV15-151039)	.008968	- 8.3	-	
104	UNIT HORIZONTAL TAIL ACTUATOR	2	83-00211	.0451		14531 (CV15-601051)	.044672	0.9		
105	ROLL FEEL ISOLATING ACTUATOR	1	83-00251	.0073		14231 (210-32277)	.008811	-17.1		
106	AUTOPILOT ACTUATOR ROLL, YAW, PITCH	3	83-00231	.0305		5758A&B 5758E&F 57582&3 (210-32230)	.04367	-30.2		
107	SPEED BRAKE ACTUATOR	1	83-00201	.0030		14622 (215-32031)	.002743	9.6		
108	LEADING EDGE FLAP ACTUATOR	8	83-00261	.0033		14753 14755 (215-72033)	.003668	-10.6		

LHS MAINTAINABILITY

ITEM NO.	COMPONENT	QUANT PER SYS	8000 PSI SYS			3000 PSI SYS		% MMH/FH CHANGE 3000 VS 8000		REMARKS/RATIONALE
			P/N	MMH/FH DEV	MMH/FH PROD	WUC (P/N)	MMH/FH PER SYSTEM	DEV	PROD	
1C9	RUDDER SERVO VALVE	1		.0054	-	14432 (215-62100-4)	.005359	0	-	
-	TUBING & FITTINGS		-	.0069	-	1423D 14239 14433 14439 14627 14629 1475F 14759 14769 45119 45139 45319 45329 45419	.013858	-50		

TOTAL 0.30

TOTAL 0.36

-16.7%

APPENDIX F

FAILURE ANALYSIS REPORTS

Contents

1984 (REV 1/77)

SPERRY VICKERS ENGINEERING TECHNICAL REPORT

PROJECT NO. 03- 802060

RELEASE DATE 19 JAN 1981

TITLE	MODEL - PART NO.	
Transfer Tube Material and Seal Changes	PV3-047-2	

REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)	PROJECT NO.	NO. OF UNITS	OBTAINED FROM
SER AA-79-069	8-1121-203		

TYPE OF FLUID: MIL-H-83282

FLUID TEMP.: Various

TEST SPEC.:

CIRCUIT NO.:

GRAPHS:

OSCILLOGRAPHS:

PHOTOGRAPHS:

DRAWINGS: 3

INTRODUCTION

The PV3-047-2 hydraulic pump has a floating transfer plate whose kidney slots are connected to the cylinder block bores by transfer tubes, Figure 1. In the initial design, these tubes were made of aluminum. The transfer tube seal at the cylinder block end, Figure 2 was an elastomer O-ring with a teflon backup ring. The bore to tube diametrical clearance was 12-30% of that specified for 3000 psi systems by MIL-G-5514F. The seal at the transfer plate end was metal-to-metal, Figure 2.

PURPOSE: The purpose of this report is to summarize transfer tube material and seal changes dictated by development test results.

CONCLUSION

(1) The use of aluminum as a transfer tube material gave unacceptable strength and wear properties.

(2) Graphitic tool steel, type 06, has been shown to be sufficiently strong and gall-resistant.

(3) Elastomer seals had insufficient life when used on the transfer tubes.

(4) Steel piston rings used as seals on both ends of the tubes, Fig. 3, reduce leakage from case to inlet and eliminate the seal life problem.

SUMMARY OF RESULTS

(1) Inspection of aluminum transfer tubes early in development testing showed cracks along the length of some tubes. Since the material was changed to tool steel, this has not been encountered.

(2) Tests with the elastomer seals on the cylinder block end showed that they began to leak excessively after 30 hours of operation.

(3) Tests showed that when pump case pressure was higher than the intake pressure, the tubes could not be prevented from having some cylical motion as they went from the high-pressure side to the intake side and back to the high pressure side. This rendered the metal-to-metal seal on the transfer plate end ineffective, resulting in no case leakage at case pressures more than about 60 psi above inlet. This occurred because all the leakage was being forced back into the pistons on the intake side of the revolution. Addition of seals at this end of the tubes alleviated this problem. The steel piston rings have been run for 120 hours with no significant wear.

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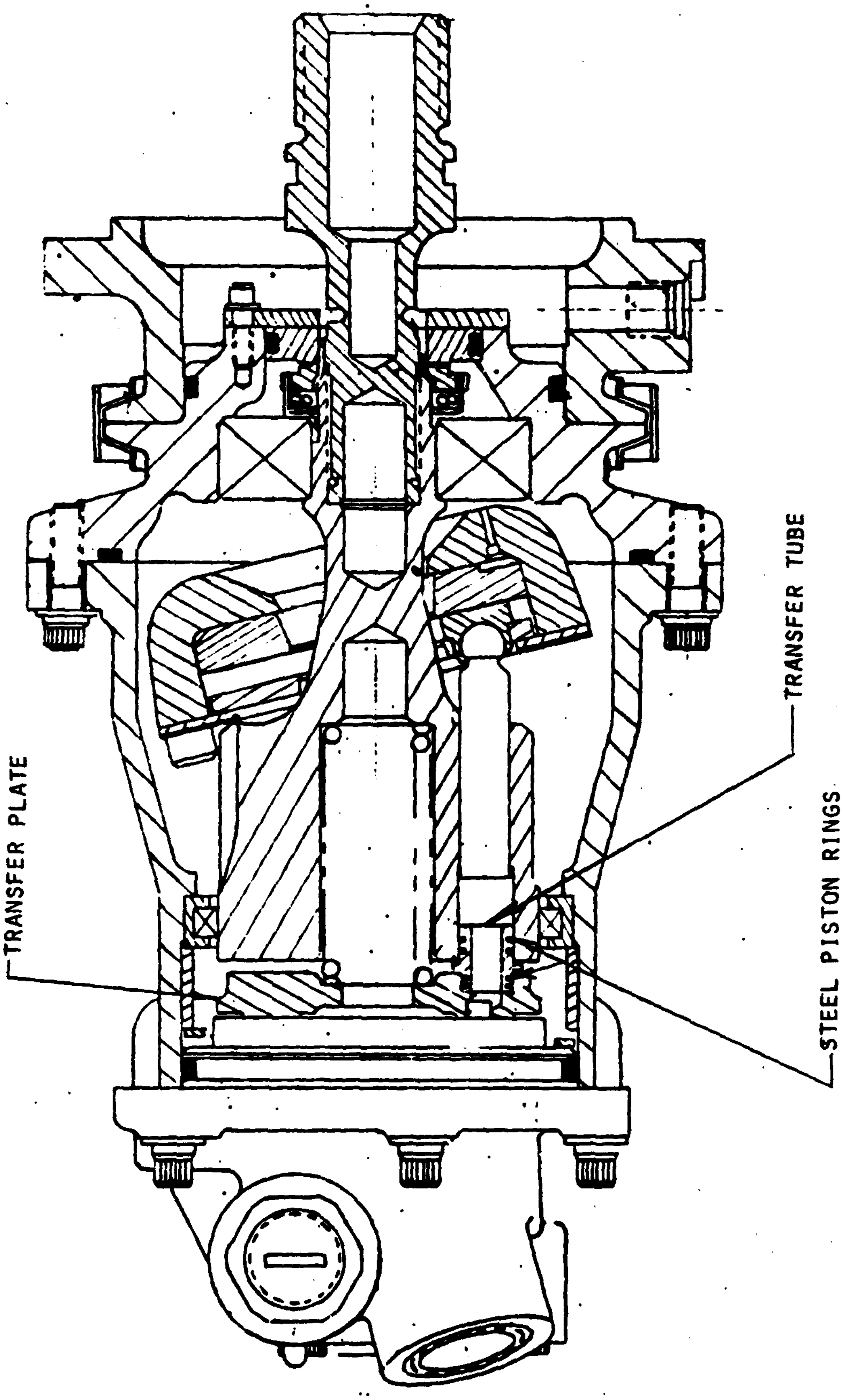
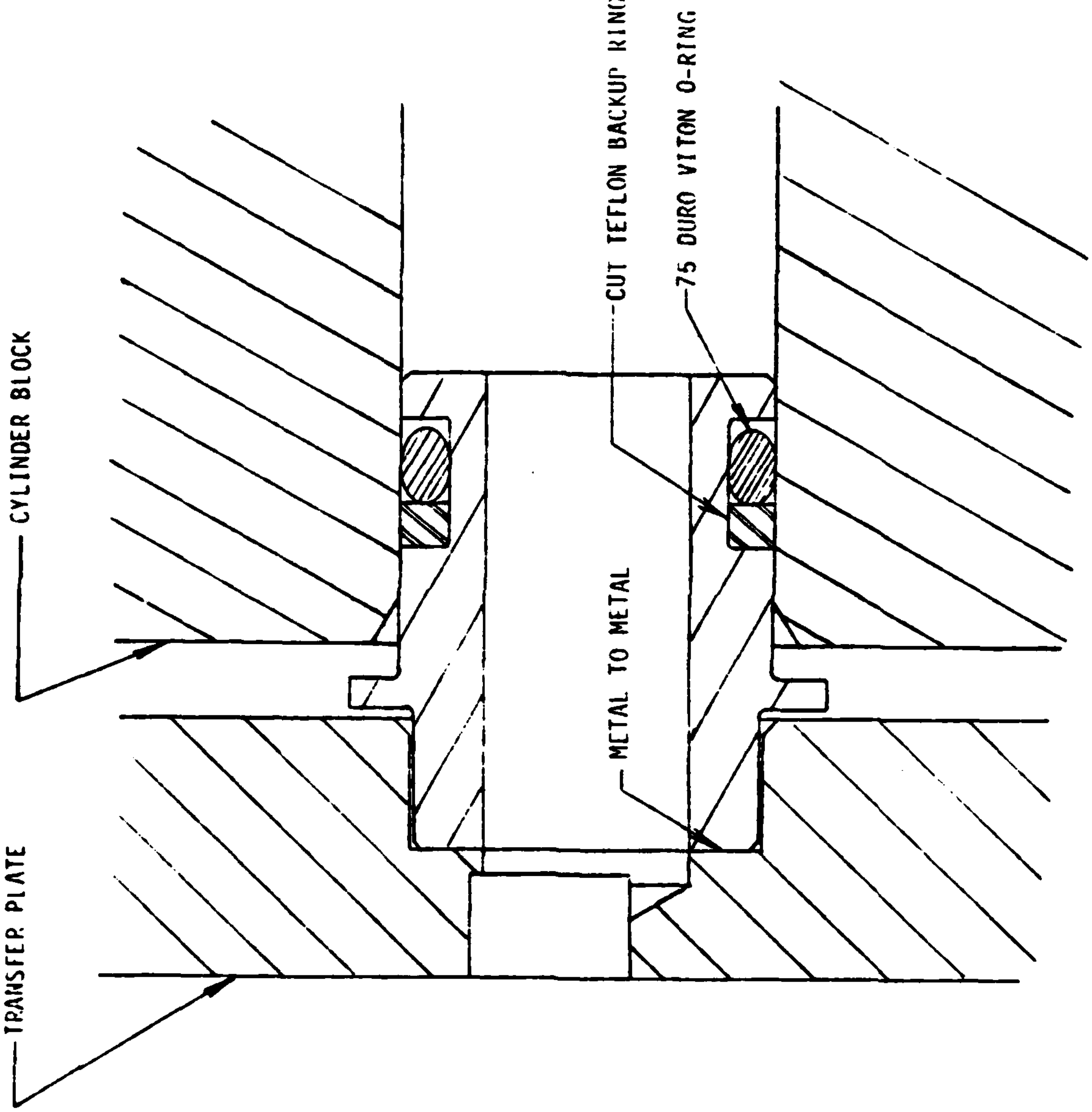


FIGURE 1 PV3-047-2 CONFIGURATION



TRANSFER TUBE SEAL CONFIGURATION No. 1

FIGURE 2

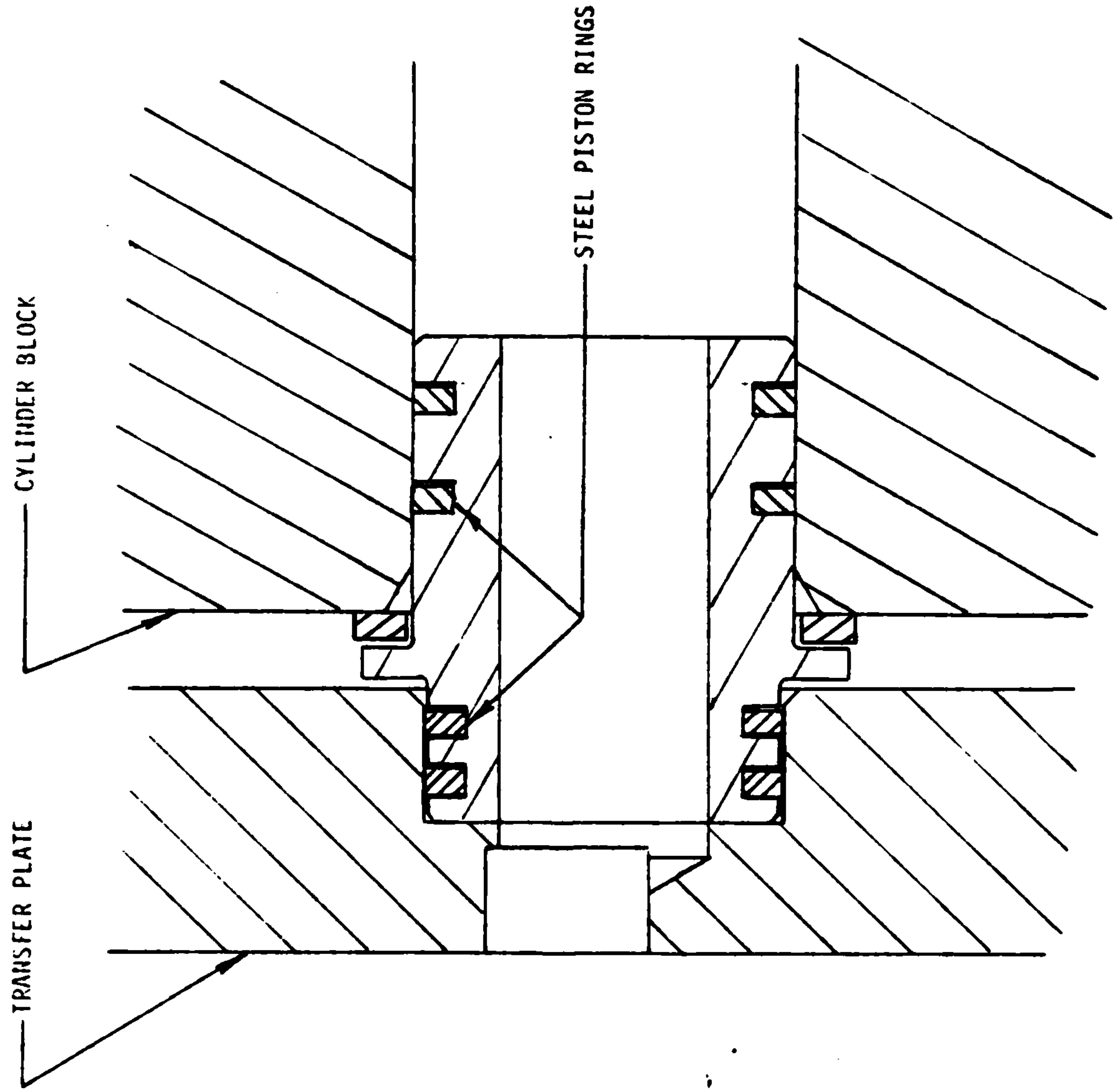


FIGURE 3 STEEL PISTON RING CONFIGURATION

1984 (REV 1/77) NADC-77108-30

PROJECT NO. 03- 802061

SPERRY VICKERS ENGINEERING TECHNICAL REPORT

RELEASE DATE 19 JAN 1981

TITLE
Pintle Bearing Brinnelling

MODEL - PART NO.
PV3-047-2

REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)
SER AA-79-069

PROJECT NO.
8-1121-203

NO. OF UNITS

OBTAINED FROM

TYPE OF FLUID
MIL-H-83282

FLUID TEMP.
Various

TEST SPEC.

CIRCUIT NO.

GRAPHS

OSCILLOGRAPHS

PHOTOGRAPHS

DRAWINGS

INTRODUCTION

Two interim pumps were delivered to Rockwell International to run their 150-hour system compatibility test. Both pumps exhibited increasing case leakage and bronze particles in the case drain filters. One pump was returned after 50 hours of cycling and the other after about 100 hours of cycling. Teardown inspection revealed that one shoe from each pump had a broken bronze ring (See Report No. 03-802063), and that each pump had a spalled high pressure pintle bearing inner race.

PURPOSE:

The purpose of this report is to summarize the results of the analysis of the pintle bearing race brinnelling.

CONCLUSION

(1) The pintle bearings on the high-pressure side do not have sufficient load-carrying capability.

(2) Cycling the pump contributes to the brinnelling. The pumps have been run extensively at steady-state conditions at Vickers without bearing damage.

(3) Analytical results showed that larger bearings are required to meet the life requirements - 204 envelope size on the high pressure side and 203 on the low pressure side, both with full complement of rollers.

SUMMARY OF RESULTS

At the end of 50 hours of cycling, the high-pressure pintle bearing was brinnelled on one of the pumps. The bearing was replaced, and the pump was disassembled again after seven hours of cycling. The new bearing showed the onset of brinnelling.

The other pump was disassembled after 100 hours of cycling, and the high-pressure pintle bearing exhibited brinnelling, but was not significantly worse than the bearing from the other after 50 hours. The pump was still operable.

Digital computer program A0011 was used to calculate the Hertzian stresses on the rollers. These calculations verified that the allowable stress levels were exceeded on the failed bearings.

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SPERRY VICKERS ENGINEERING TECHNICAL REPORT

PROJECT NO. 03-802062

RELEASE DATE 19 JAN. 1981

TITLE: Pump Leakage with Shoe Balance Plate	MODEL - PART NO.: PV3-047-1
REFERENCES (INCLUDE R.E.O., SER. OR OTHERS): SER AA-79-069	PROJECT NO.: 8-1121-203
NO. OF UNITS:	OBTAINED FROM:
TYPE OF FLUID: MIL-H-83282	FLUID TEMP.: Various
TEST SPEC.:	CIRCUIT NO.:
GRAPHS:	OSCILLOGRAPHS:
PHOTOGRAPHS:	DRAWINGS: 2

INTRODUCTION

In the original design of the 8000 psi pump, the piston shoes were encased in a riveted plate assembly consisting of a balance plate, a holddown plate, and a spacer plate, Figure 1. The entire plate assembly rotated, so that a hydrodynamic oil film was established between the balance plate and the wear plate. This accomplished the purpose of limiting the shoe motion relative to the balance plate.

PURPOSE

The purpose of this report is to summarize the effect of shoe balance plate configuration on case leakage.

CONCLUSION

Yoke bending with the balance plate shoe configuration induces case leakage. In order to use this configuration, the yoke must be reinforced.

SUMMARY OF RESULTS

The pump was tested with the balance plate shoe configuration, and case leakage was observed much higher than that allowed to meet heat rejection requirements.

This shoe configuration was a departure from the standard configuration used in Vickers 3000 psi pumps. The leakage tests for the PV3-047-1 were repeated with this standard shoe configuration, shown in Figure 3. The results showed a case leakage reduction of about 1 gpm from the leakage observed with the plate configuration.

Yoke bending calculations indicated that the yoke may bend as much as .0008 when loaded. When the balance plate assembly was used, this deflection would open up leakage paths as shown in Figure 2.

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FIGURE 1 Shoe Balance Plate Design

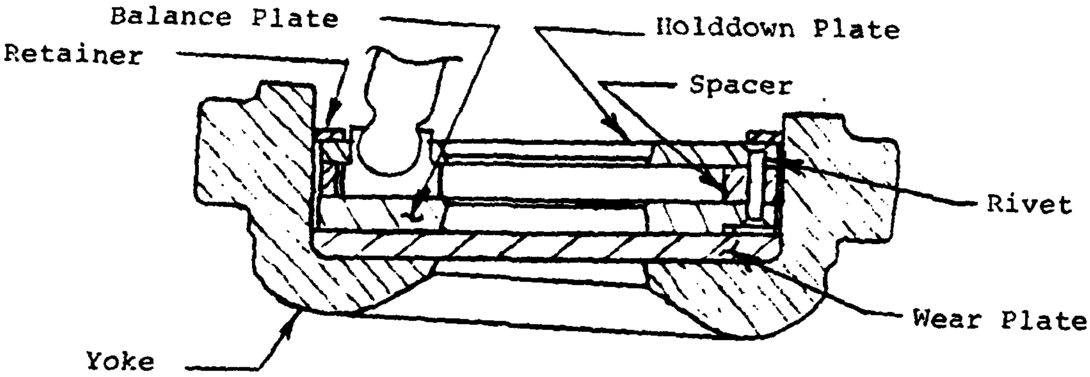
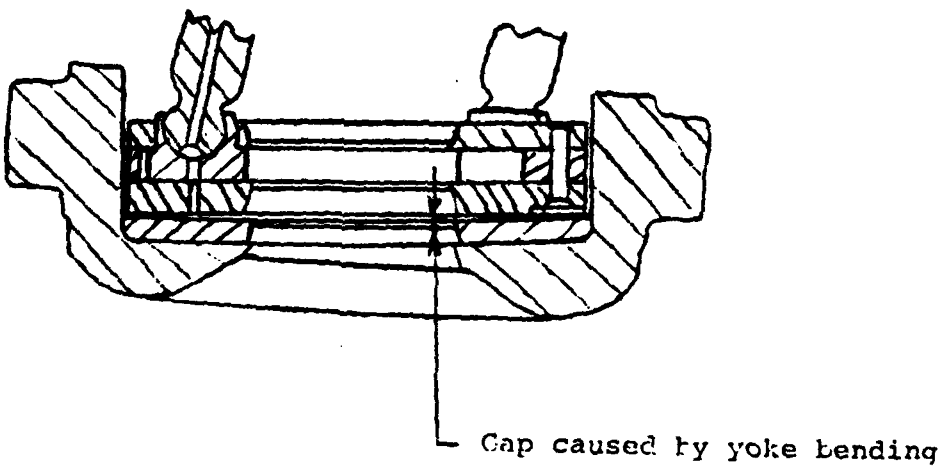


FIGURE 2 Leakage Path Opened Up By Yoke Bending



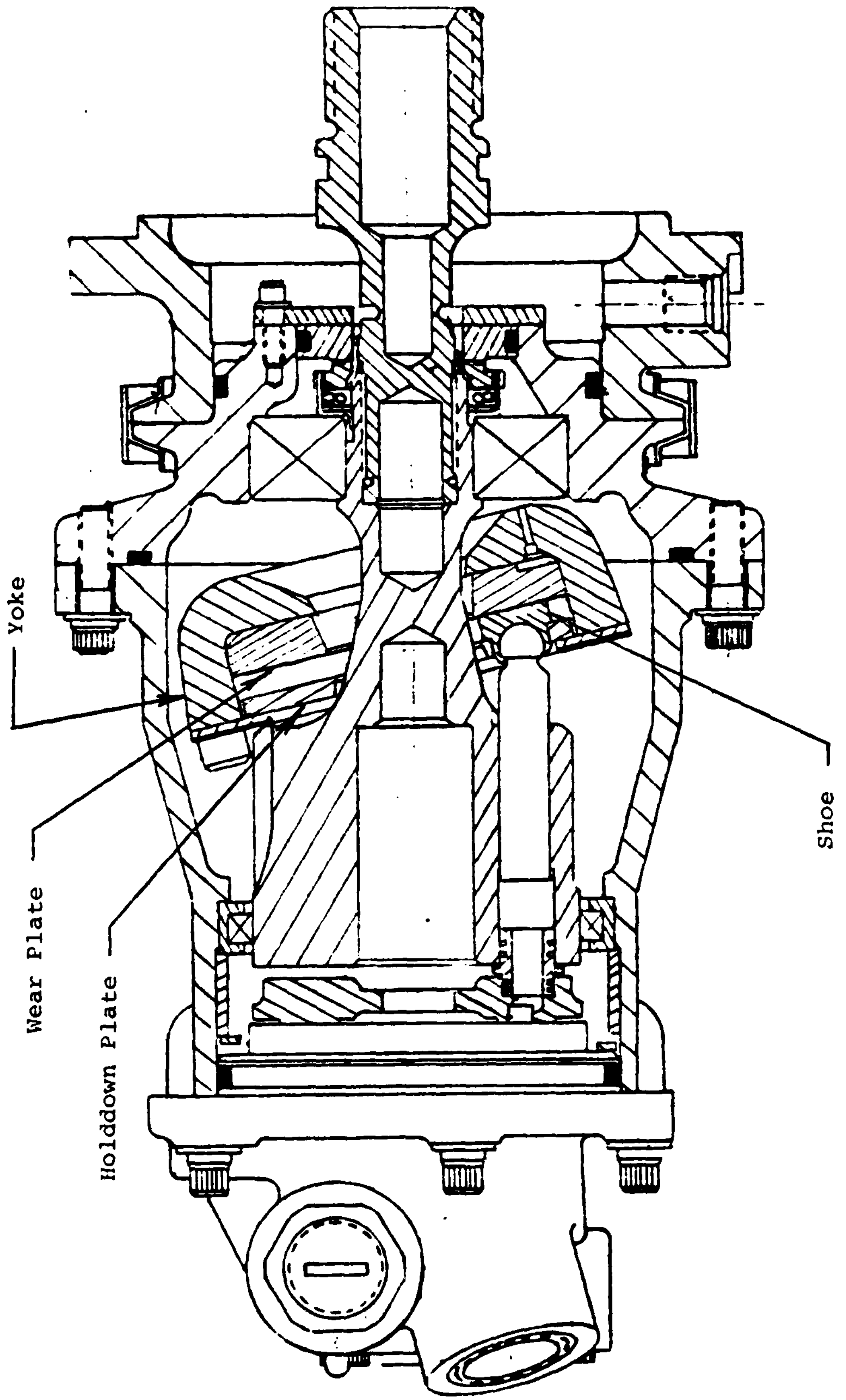


FIGURE 3 Standard Vickers Shoe Configuration

1984 (REV 1/77)

NADC-77108-30

PROJECT NO. 03- 802063

SPERRY VICKERS ENGINEERING TECHNICAL REPORT

RELEASE DATE 19 JAN 1981

TITLE		MODEL – PART NO.	
Shoe Failure		PV3-047-2	
REFERENCES (INCLUDE R.E.O., SER. OR OTHERS) SER AA-79-069	PROJECT NO. 8-1121-203	NO. OF UNITS 2	OBTAINED FROM Jackson

TYPE OF FLUID: MIL-H-83282

FLUID TEMP.: 200-220°F

TEST SPEC.:

CIRCUIT NO.:

GRAPHS:

OSCILLOGRAPHS:

PHOTOGRAPHS:

DRAWINGS:

INTRODUCTION

Two interim pumps were delivered to Rockwell International to run their 150-hour compatibility test. Both pumps exhibited increasing case leakage and bronze particles in the case filters. Teardown inspection revealed that one shoe from each pump had a portion of the bronze ring cracked which resulted in excessive leakage and eventually the removal of a significant part of the bronze ring.

PURPOSE

The purpose of this report is to summarize the observations during disassembly of the pumps and to summarize reasons for the failures.

CONCLUSION

1. The shoe failures were due to voids of the braze, between the bronze ring and the steel shoe.
2. Improvement is required in the quality of brazing to minimize voids and assure that the braze joint between the steel shoe and bronze ring is homogeneous to prevent oil pressure getting under the bronze ring and causing cracking. Quality assurance can be verified by instituting the quality "step plan" on the process sheet.

SUMMARY OF RESULTS

One of the units exhibited high leakage at the end of about 46 hours of cycling. Disassembly showed that one of the shoes had a piece missing from the bronze ring.

The other pump discharged a piece of bronze through the case drain during the first 50-hour leg of the test. It continued to run through completion of about 100 hours of cyclings after which it was disassembled. It was found that the piece of bronze had come from a shoe.

Examination of the broken shoes and sectioning of another shoe in the batch revealed a large number of voids under the bronze ring. There were large voids next to the post, Figure 1, because the bronze ring was installed inverted, so that the .050 x 45° chamfer was against the post. Other voids occurred randomly throughout the braze, and were apparently due to poorly developed brazing technique. Experimentation with the brazing parameters reduced the number of voids in subsequent shoes.

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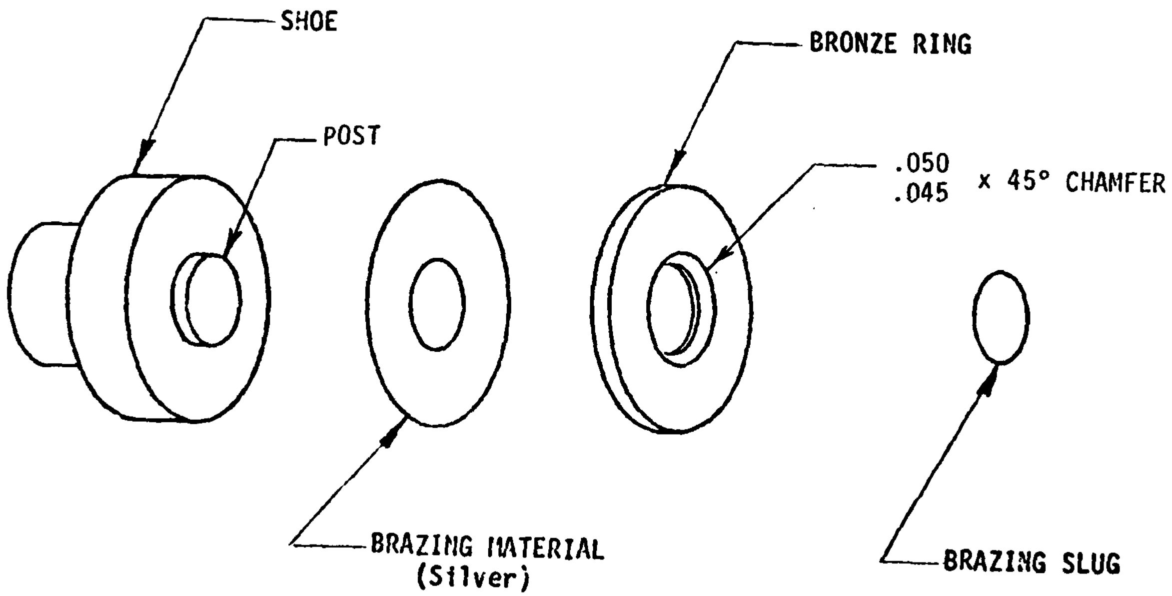
Report No. 03-802063

SHOE BRAZING PROCEDURE
FIGURE I



1984 (REV 1/77)

SPERRY VICKERS ENGINEERING TECHNICAL REPORT

PROJECT NO. 03- 812007

RELEASE DATE

TITLE	MODEL - PART NO.
Pin-Hole Leak in 7075-T6 Valve Block (PN 570934)	PV3-047-2

REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)	PROJECT NO.	NO. OF UNITS	OBTAINED FROM
AA-79-069	8-1121-203	1	

INTRODUCTION

Hydraulic pump serial number MX-346581 was one of two pumps delivered to Rockwell International to run Lightweight Hydraulic System (LHS) compatibility tests. The valve block material was 7075-T6 aluminum. This pump was returned after about 87 hours of accumulated time at Rockwell with a pin-hole leak in the valve block.

TYPE OF FLUID	MIL-H-83282
FLUID TEMP.	Various
TEST SPEC.	
CIRCUIT NO.	
GRAPHS	
OSCILLOGRAPHS	
PHOTOGRAPHS	
DRAWINGS	1

PURPOSE

The objective of this report is to present the results of investigation of the leakage.

CONCLUSION

The leak was caused by non-homogeneity in the material. The material used for future high pressure parts should be inspected for uniformity.

SUMMARY OF RESULTS

The leak was through the material around the compensator annulus machined in the valve block and was not visible except under a 30-power microscope. Under microscopic examination the leak appeared as a pore. The material showed no sign of overloading or fatigue, such as deformation or cracking. This was compatible with stress calculations - maximum hoop stress was 20% of the yield strength, and alternating stress was about 30% of the fatigue strength.

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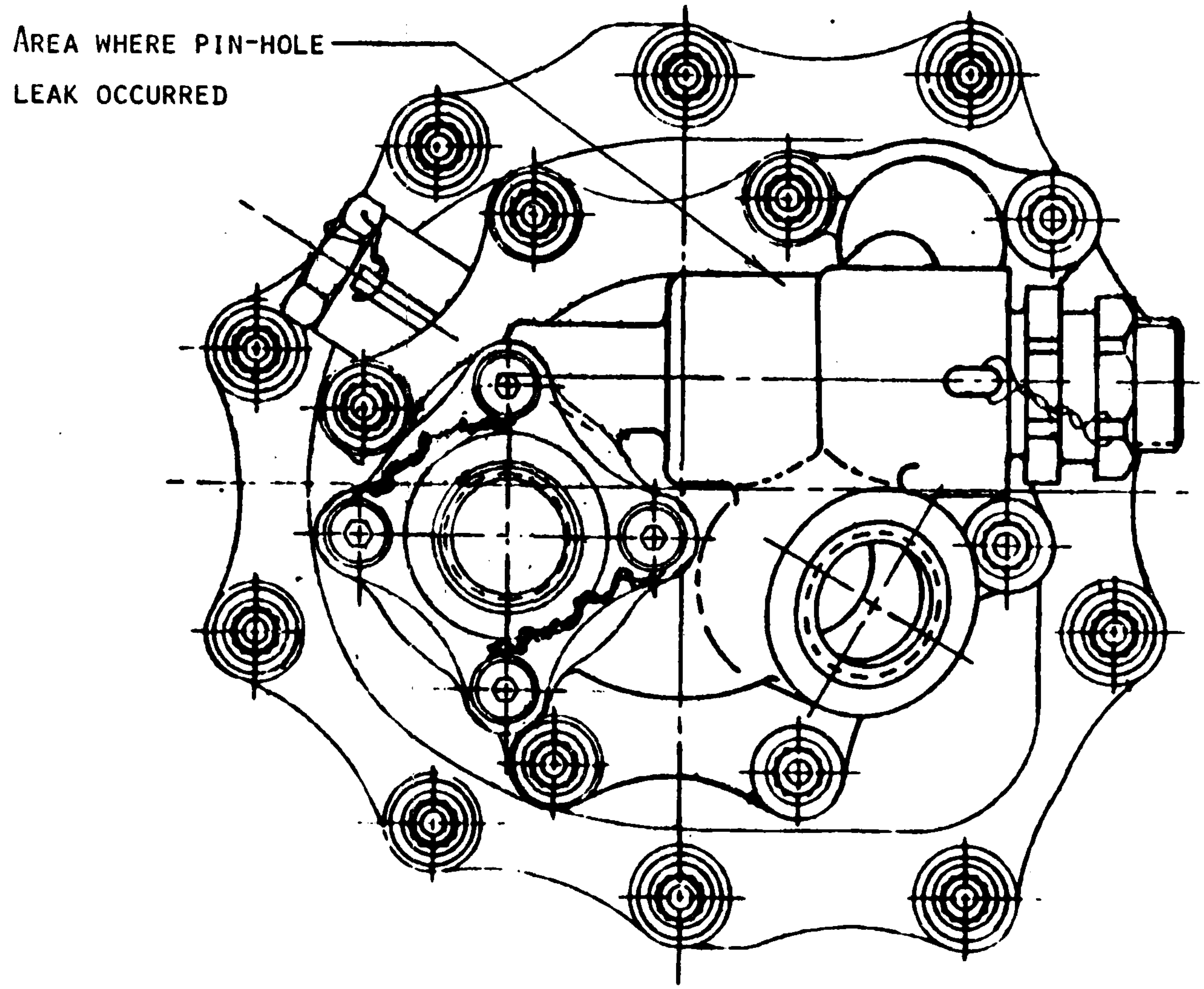
FIGURE 1 LOCATION OF PIN-HOLE LEAK



1984 (REV 1/77)

SPERRY VICKERS ENGINEERING TECHNICAL REPORT

PROJECT NO. 03- 812019

RELEASE DATE

TITLE	MODEL - PART NO.
Valve Block Control Pressure Bore Erosion (PN 570934)	PV3-047-2

REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)	PROJECT NO.	NO. OF UNITS	OBTAINED FROM
AA-79-069	8-1121-203	1	

INTRODUCTION

Hydraulic pump serial number MX-348168 was one of two interim pumps delivered to Rockwell International to run their Lightweight Hydraulic System (LHS) compatibility tests. This pump was returned after about 120 hours with a leak between the housing and valve block. The valve block was 7075-T6 aluminum.

TYPE OF FLUID: MIL-H-83282

FLUID TEMP.: Various

TEST SPEC.:

CIRCUIT NO.:

GRAPHS:

OSCILLOGRAPHS:

PHOTOGRAPHS:

DRAWINGS: 1

PURPOSE

The objective of this report is to present the results of investigation of the leak.

CONCLUSION

The leak was due to porosity or non-homogeneity of the material.

SUMMARY OF RESULTS

The control pressure in the PV3-047-2 is transmitted to the actuator piston in the housing by means of a transfer tube, as demonstrated in Figure 1. The static seals at the ends of the transfer tube are accomplished by O-rings and backup rings with bore-rod clearances about half that used in 3000 psi systems. The material in the wall of the valve block bore developed patches of erosion that opened up leakage paths around the seal. Microscopic examination revealed a large amount of porosity in this area, and this allowed leakage paths to start the erosion.

COPIES TO

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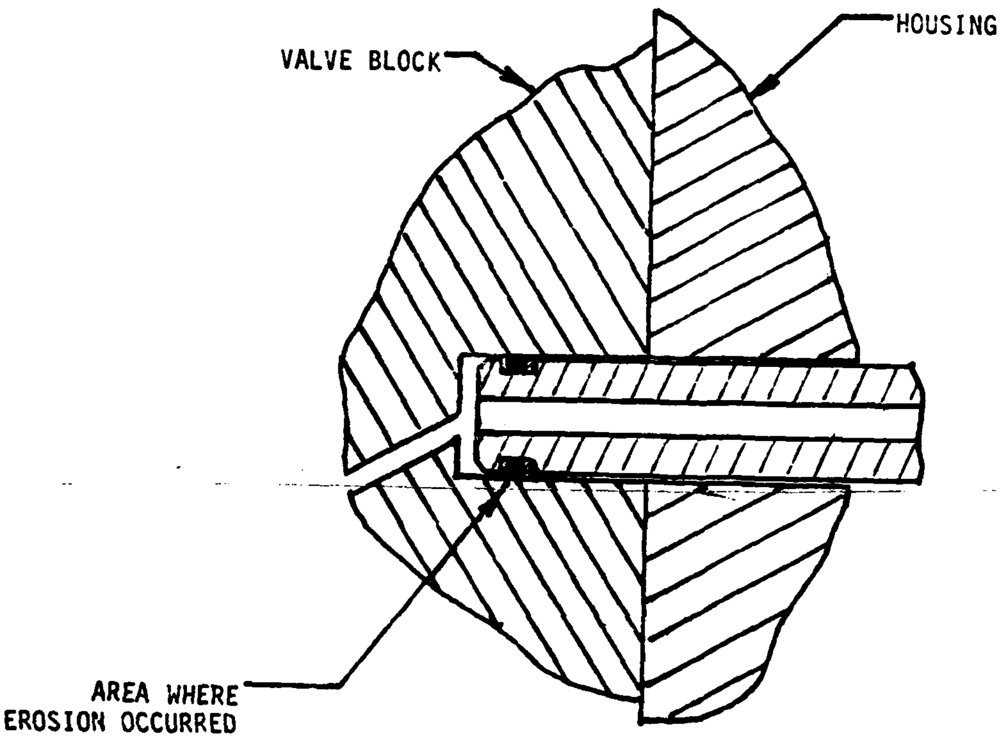
FIGURE 1 LOCATION OF MATERIAL EROSION



RELIABILITY ENGINEERING FAILURE REPORT

EQUIPMENT NAME	PART NO.	SERIAL NO.	PROGRAM (MODEL)
AFCS ACTUATOR 83-00231	83-00234-107 END CAP	—	LHS

TEST CONDITIONS AT FAILURE			TYPE TEST		REPORT NO.
TEST ACTUATOR	PRESSURE	11,200 psig	SEAL EVALUATION		1
	FLUID TEMP	80 °F	ACCEPTANCE	X	DATE OF FAILURE
	LEAKAGE	MASSIVE	COMPONENT		7-21-80
	SEAL TEMP	80 °F	QUALIFICATION		

PRESSURE BETWEEN TWO STAGE SEALS	N/A psig	BLOCK NO.	N/A	STROKE	N/A
LOAD CYLINDER PRESSURE	N/A psig	NO. CYCLES	N/A	LOAD (%)	N/A
		TEST TIME	N/A		

FAILURE DESCRIPTION

PROOF PRESSURING OF BY-PASS VALVE WAS IN PROGRESS. AT 11,200 PSI LARGE QUANTITIES OF HYD FLUID SPEWED FROM THE RH END CAP.

VOUGHT LAB FINDINGS | DISASSEMBLY TIME

THE END CAP HAD BOWED UNDER PRESSURE TO THE POINT AT WHICH THE HYD FLUID BLEW OUT PAST THE STATIC SEAL.

CORRECTIVE ACTION

ORIGINAL PART WAS OUT OF 7075 T651. WILL MAKE NEW PARTS OUT OF STEEL.

ORIGINATOR	DATE	LAB RESULTS	DATE	CORRECTIVE ACTION DOCUMENTATION
A. M. HILL (WDP)	7-23-80			INCORPORATION

RELIABILITY ENGINEERING FAILURE REPORT

EQUIPMENT NAME	PART NO.	SERIAL NO.	PROGRAM (MODEL)
AFCS ACTUATOR 83-00231	S30650-116-14 ROD SEAL	——	LHS

TEST CONDITIONS AT FAILURE			TYPE TEST		REPORT NO.
TEST ACTUATOR	PRESSURE	8000 psig	SEAL EVALUATION		2
	FLUID TEMP	250 °F	ACCEPTANCE		DATE OF FAILURE
	LEAKAGE	MODERATE	COMPONENT		
	SEAL TEMP	250 °F	QUALIFICATION	X	4-1-80

PRESSURE BETWEEN TWO STAGE SEALS	N/A psig	BLOCK NO.	——	STROKE	10%
LOAD CYLINDER PRESSURE	N/A psig	NO. CYCLES	40,000	LOAD (%)	10
		TEST TIME	1600		

FAILURE DESCRIPTION

WITH SYS RETURN PRESS (90 PSI) EXCESSIVE LEAKAGE (7.5 DROPS/MIN) WAS OBSERVED OUT THE LH SIDE AFT ROD SEAL (SPRING END).

VOUGHT LAB FINDINGS

DISASSEMBLY TIME 4-2-80

APPROX 1/4 OF THE CAP STRIP ON BOTH THE ROD END AND SPRING END ROD SEAL WERE MISSING. THERE WAS EVIDENCE ALSO THAT THE PISTON ROD WAS RAMPING UP DUE TO INTERFERENCE OF THE 83-00234-121 (FLANGE) WITH THE 83-00234-115 RETAINER. THE RAMPING ACTION SEEMS TO HAVE CAUSED EXCESSIVE SEAL WEAR.

CORRECTIVE ACTION REPLACED CAP STRIPS; EXTRA CLEARANCE WAS OBTAINED BY FILING THE 83-00234-115 RETAINER IN THE AREA OF INTERFERENCE.

should be -111?

ORIGINATOR	DATE	LAB RESULTS	DATE	CORRECTIVE ACTION DOCUMENTATION
A.M. HILL	4-2-80			INCORPORATION

Internal Memorandum NADC-77108-30

Bendix Electrodynamics Division

North Hollywood

Date 12/3/80 Letter No. HYD-506-80

To R. L. Vick

From J. Toon

Subject Rockwell 8000 PSI Valve, P/N 3321472

The subject valve was received into R & O on 11/10/80 after being returned from Rockwell International. The unit was returned to:

1) Reduce internal leakage.
2) Determine source of valve failure that occurred after 1043 cycles.
3) Reduce the pull-in and drop-out voltages.

Internal Leakage: During assembly and test prior to the initial delivery of the valve assembly to Rockwell, the valve housing and slide were subjected to numerous modifications. Resultant burrs (etc.) in the housing bore and slide O.D. were removed by lightly lapping the surfaces. As a result, the lap clearance and internal leakage became excessive. To bring the lap clearance into the .000110 - .000150 diametrical clearance range on the drawing, the slide O.D. was stripped, chrome plated IAW QQ-C-320, Class 2, and lapped to achieve the required final clearance.

Valve Failure:

1. Operate to determine failure characteristics at ambient temperature and 3000 psi --
   - S1 --Operated normally
   - S2 -- Did not operate

2. Disassemble S1 and S2 --
   - S1 --The spacer pin had an indentation from the pilot valve ball
   - S2 --The spacer pin had an indentation from the pilot valve ball and was swaged or mushroomed on that end. Hardness reading showed that these pins were not hardened IAW the print (Rc 50 min.).. In the pilot valve, there was no ball stroke. Evaluation of the valve pin (a modified drill) showed the fluted end of the drill to be battered down with a portion sheared off.

3. Rework -- Replaced the spacer pins in S1 and S2 with new pins hardened to Rc 50 minimum. Replaced the pilot valve pins with a triangular cross-section pin giving a larger surface for the pilot valve balls to push on.

Reduce Pull-in/Drop-out Voltages: The core plunger protrusion, ball stroke and spacer pin protrusion were minimized to minimize the total air gap. The pull-in/drop-out voltages were reduced to 12.0V/4.4V and 14.5V/5.0V for S1 and S2 respectively at ambient temperature and 8000 psi.

John Toon

J. Toon:sah

Internal Memorandum

NADC-77108-30

Bendix Electrodynamics Division

North Hollywood, Californ

Date Jan. 27, 1981 Letter No. HYD-35-81

To Ralph Vick

From John Toon

Subject Rockwell 8000 psi 3-way Valve, P/N 3321473

The subject valve was received into R&O on 1/5/81 after being returned from Rockwell International. The valve was returned because it failed to operate after being subjected to 40,000 impulse cycles at 10,700 psi while in the de-energized state.

The tasks performed on the valve while in R&O were:

1) Determine source of valve failure and repair.

2) Reduce pull-in and drop-out voltages and up-grade the solenoid/pilot valve section to current design status.

3) Cycle:operate at 8000 psi and ambient temperature to verify unit integrity.

Conclusion

The valve failure is attributed to failure of the Solenoid spacer pin, P/N 3321871 which was not properly heat treated (R_C 20 vs requirement of R_C 50 min). Replacement of this pin along with reduction of the total solenoid air gap resulted in an approximate 10 volt Solenoid pull-in voltage. Integrity of the valve was verified by successful completion of 24,248 cycles at 8000 psi and ambient fluid and air temperatures.

1) Determine Source of Failure

A. Operated to determine failure characteristics at ambient temperature and 3000 psi fluid pressure. With 24 volts applied to the solenoid there were not any changes in the valve conditions. Return was open to cylinder indicating that the slide was in the de-energized position.

B. Measured 85.9 ohm across leads on the solenoid. There were not any shorts (lead to case).

C. Removed slide and spring. Visual inspection showed two light scratches across two lands on the slide, but the slide moved freely in the bore.

D. Disassembled solenoid/pilot valve section. The spacer pin was battered (mushroomed) down which eliminated all solenoid air gap. The pilot valve had .009 ball stroke. These conditions are shown in Figure 1.

E. Other than the battered spacer pin, no other condition was found that could have caused valve failure.

The spacer pin for the subject 3-way valve was installed and delivered to Rockwell prior to discovery that the lot of spacer pins manufactured for the 3-way and 4-way valves were not properly heat treated. Measurements made on a pin removed from a failed 4-way valve showed a reading of less than R_C20. A new spacer pin was manufactured per print (R_C 50 min) and installed.

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Internal
Memorandum NADC-77108-30

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Date Jan. 27, 1981 Letter No. HYD-35-81

2) Reduce Pull-in and Drop-out Voltages and Upgrade Status

The core plunger protrustion, ball strike and spacer pin protrusion were minimized to minimize the total air gap. With a total air gap of .009 inch maximum, the pull-in/drop-out voltages were 10.6 volts/3.5 volts respectively. Figure 2 shows the current design configuration for the valve's air gap.

In addition to reducing the total air gap in the solenoid/pilot valve section the pin in the pilot valve was re-designed. The new pin design has a triangular cross-section with a hardness of R_c 55 min. The original pin design utiliz a drill modified to the required length. The intent was for the drill flutes t allow fluid passage in the pilot valve. All drills found to date had flutes approximately .25 inch long, too short for the valve. As a result the remainde of the drill rod had a flat machined on it making the part difficult to make an non symmetrical.

3) Cycle

Conditions: 8000 psi inlet at ambient fluid and air temperature.

Cycle Rate: 12 cycle/minute

Applied Voltage (to solenoid): 24 volts

Summary of Results:

After ---- Cycles		leakage cc/min P-C	C-R	Pull-in Volts	Drop-out Volts
0	(ATP Results)	6.0	2.5	10.6	3.5
1000	Cycles	11.5	5.5	-	-
2081		15.0	6.3	-	-
5,687		14.5	6.8	10.1	-
10,112		13.0	6.3	9.9	-
15258		15	7.3	9.9	-
20408		15	7.4	9.9	-
24248	End of Test	20.5	7.5	9.9	-

After the first 5000 cycles the solenoid/valve section stabilized without any additional significant changes. Visual inspection of the spacer pin shown that the ball formed a natural coined surface on the end of the pin. The depth (.001 measured) of this natural coining should be taken into consideration in the air gap of future hardware.

John Toon

John Toon

JRT:mjb

cc:

R. V. Lukas

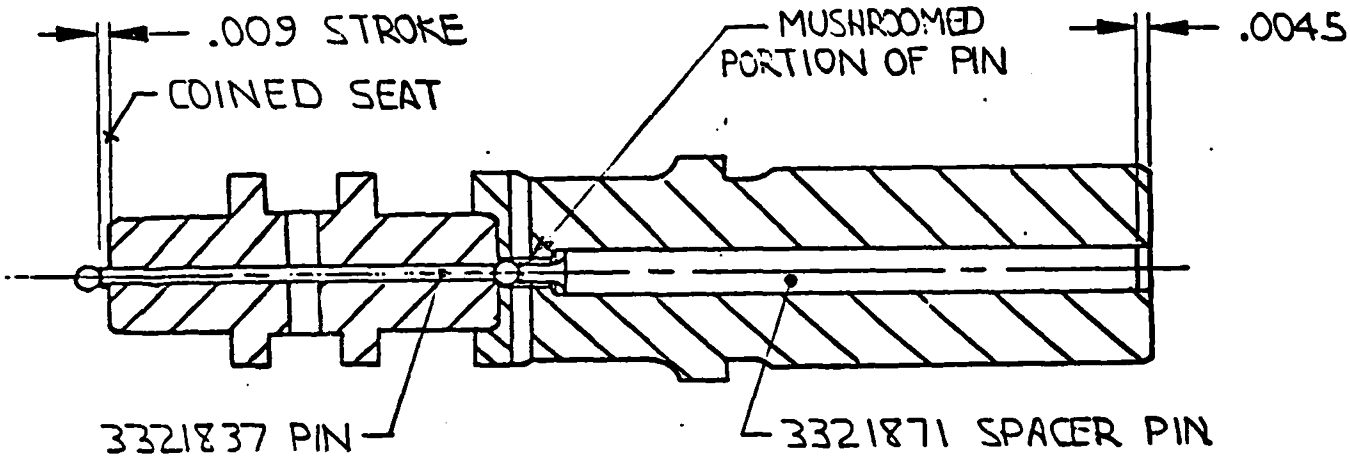

FIGURE 1
FAILED UNIT

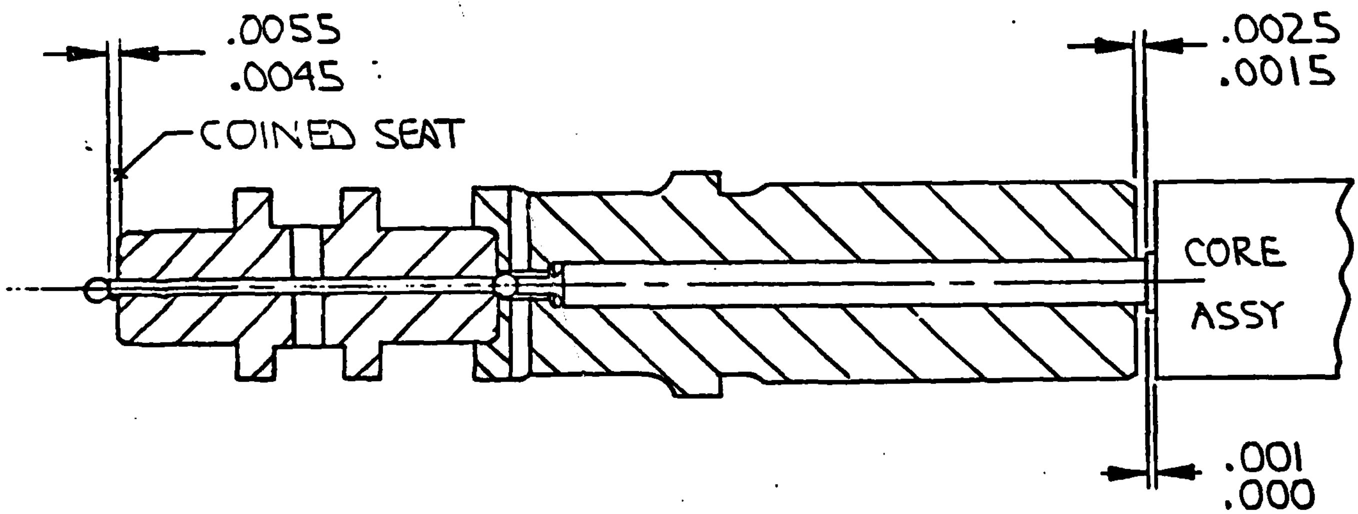

FIGURE 2
CURRENT CONFIGURATION

Internal Memorandum

NADC-77108-30

Bendix Electrodynamics Division

North Hollywood, California

Date Jan. 27, 1981 Letter No. HYD-36-81

To Ralph Vick

From John Toon

Subject Rockwell 8000 psi 4-way Valve, P/N 3321472

The subject valve was received into R&O on 1/20/81 after being returned from Rockwell International (hand carried by Bernie Holland). The valve was returned because Solenoid No. 2 (S2) failed after 2900 cycles in a endurance test at 9000 psi preceded by 475 successful speed brake cycles. The source of failure and the repair method are discussed below.

Conclusion

It was found that the design of the solenoid spacer P/N 3321841 allowed the pilot valve ball to move into an off center position in the ball guide section of the spacer. The pilot (return) ball was able to move into a position which could jam the spacer pin preventing solenoid/pilot valve operation. Redesign of the spacer to prevent the pilot (return) ball from being located in this position is complete. New parts are presently in the fabrication cycle.

Following is a summary of tests performed before disassembly of the returned unit:

1) At 3000 psi: S1 energized twice
   S2 energized twice
   Normal operation

2) At 6000 psi: S2 energized twice
   Normal operation

3) At 8000 psi S2 energized twice
   S1 energized 4 times
   S2 energized
   Normal operation

4) At 9000 psi: S2 energized twice
   Normal operation

5) Set up for cycling S2 at 8000 psi:

   a) S2 cycled between 10 and 30 times and failed
   b) S1 cycled (manually) once
   c) S2 cycled and failed after two cycles
   d) Repeat b)
   e) S2 cycled and failed after five cycles
   f) Repeat b)
   g) S2 cycled and failed after seven cycles
   h) S1 cycled 20 times. Normal operation
   i) S2 failed to operate at 8000 psi, 5000 psi, 3000 psi, 3000 psi, 8000 psi (one cycle each)

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Date Jan. 27, 1981 Letter No. HYD-36-81

6) S2 was disassembled. Figure 1 shows an exaggerated view of the condition that was found. The pilot ball was able to locate itself in a positon at the fluid return hole jaming the spacer pin. A corresponding mark was found on the spacer pin showing the off center position of the ball in the spacer.

Figure 2 shows an exaggerated view of the redesigned spacer. Basically the cross drilled fluid return holes were moved further away from the pilot valve seat and the hole size was decreased (additional holes were added to prevent added pressure drop through the spacer) to prevent the ball from shifting too far to the side.

Spacers made to the new design are presently in the fabrication cycle. Upon completion they will be matched to the spacer pins (the damaged pin discussed above will be replaced) taking into consideration that the natural coining of the pilot ball into the pin will require an additional .001 inch in the initial air gap.

John Toon

John Toon

JRT:mjb

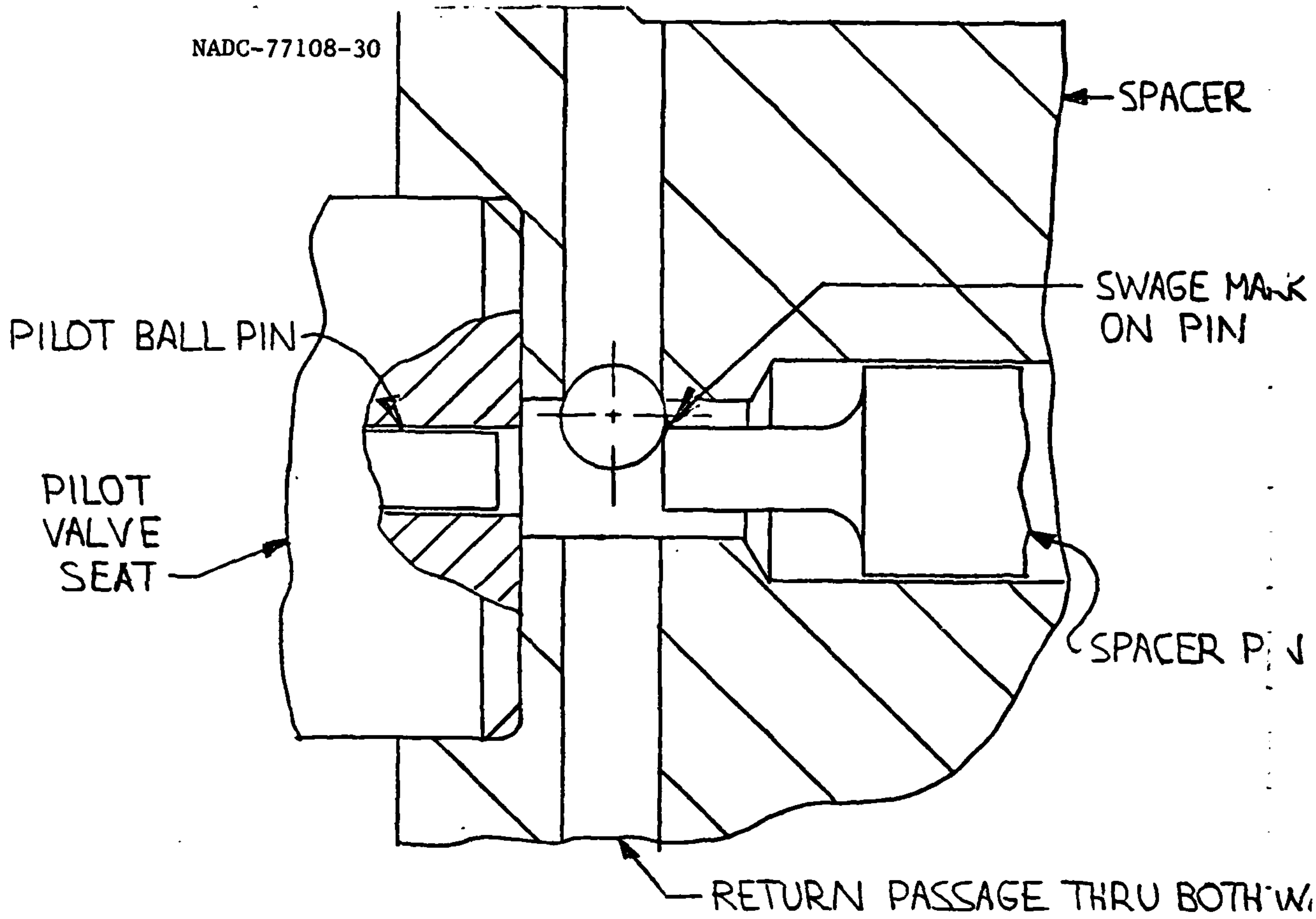

FIGURE 1

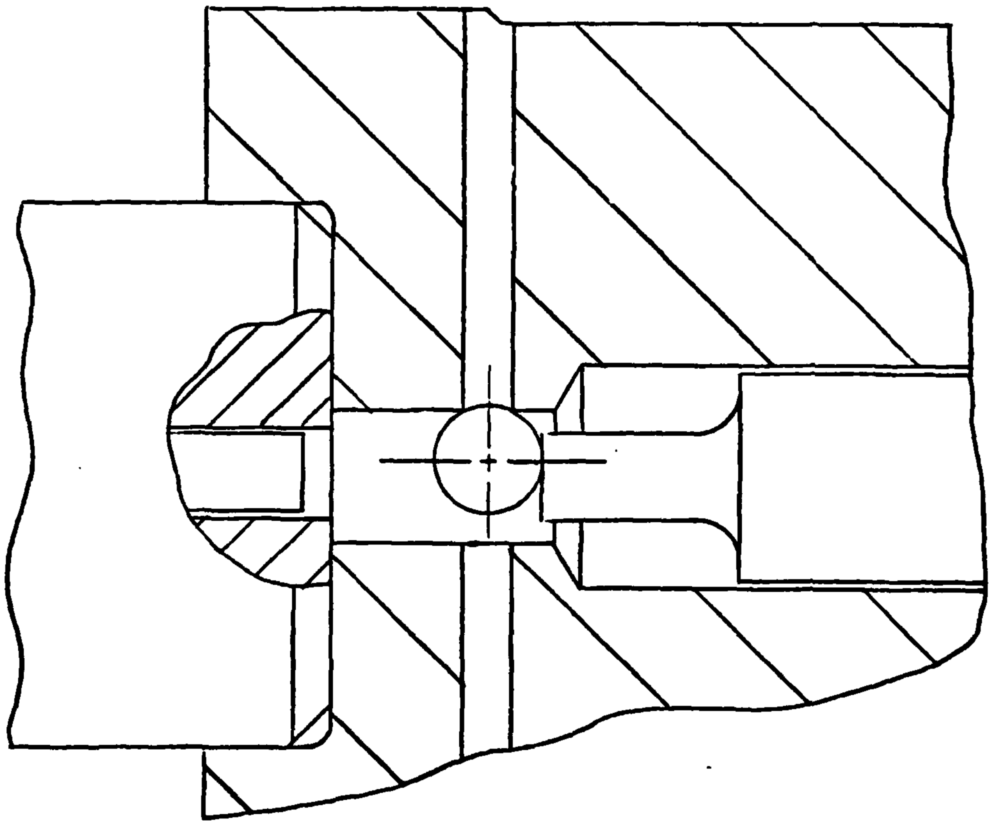

FIGURE 2

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